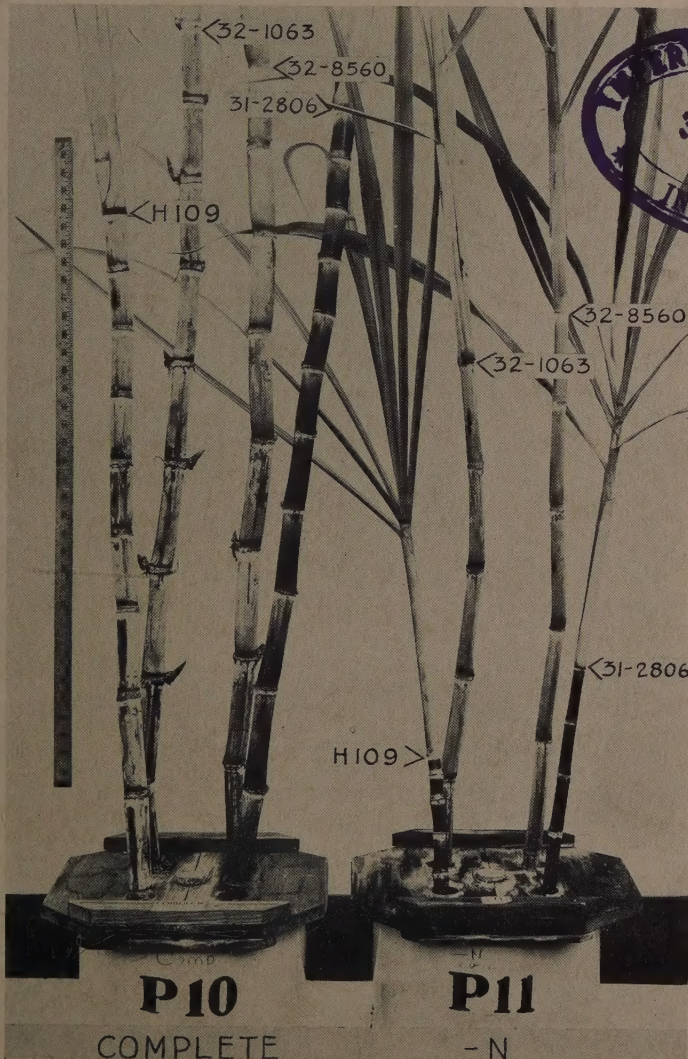# THE HAWAIIAN PLANTERS' RECORD

Sugar cane varieties manifest differences in growth, yields, and tolerance to nutrient deficiencies.

SECOND QUARTER 1941

HAWAIIAN SUGAR PLANTERS' ASSOCIATION

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EXPERIMENT STATION COMMITTEE

THE HAWAIIAN
PLANTERS' RECORD

In This Issue:

Some Considerations of the Polarographic Method of Quantitative Analysis:

The polarographic method of chemical analysis differs from spectrographic analyses in that current-voltage relationships of a solution under observation pass through specific orderly and characteristic changes as metallic or organic constituents of the solution progressively deposit out and register their presence or their concentration in the process of dissolution. In spectroscopy a photograph of the spectrum of an incandescent substance is imposed upon a sensitive plate which, with calibrated reference adjuncts, renders it possible to "analyze" the plate and thereby determine the character and relative concentration of chemical elements originally present in the specimen.

These two methods of analysis are complementary because one may supplement the other or, at times, replace the other, depending upon the analyses to be performed.

Spectrographic studies have been described from time to time in this journal. The current discussion features a comprehensive exposition of the theory and practice of polarographic chemical analyses.

Varietal Differences of Sugar Cane in Growth, Yields, and Tolerance to Nutrient Deficiencies:

The varieties H 109, 31–2806, 32–1063 and 32–8560 were grown in a complete nutrient solution and in solutions lacking each of the following elements: nitrogen, phosphorus, potassium, calcium, magnesium, sulphur, iron, manganese, and boron. The development of nutrient deficiency symptoms and the detrimental effects on cane growth, cane and sugar yields, and juices of each variety in the various deficiency series are discussed. It is interesting to note that some varieties manifested a much higher degree of tolerance to certain deficiencies than others and that varieties have different nutritional requirements.

Sorption of Potassium and Ammonium by Hawaiian Soils:

Plant nutrients may be leached from soils wherever rain or irrigation water penetrate the soil to depths below the root zone. Where such penetration occurs the ability of the soil to unite with added soluble fertilizer salts is of major importance, for by this means leaching is greatly retarded.

This paper deals with a study of factors influencing the retention of soluble bases by soils. The factor of greatest importance in the retention of potassium appears to be the level of available potassium in the soil. Other factors shown to influence the sorption of potassium and also that of ammonium are the concentrations of these salts in water penetrating the soil, the rate of penetration and the degree of base saturation, or acidity of the soil.

Contributions of the Entomologists to Hawaii's Welfare:

Many insects coming from distant lands will almost always be more destructive in Hawaii than in their places of origin if suitable food plants are present. Our equable climate, small native insect fauna and great isolation peculiarly combine to favor the multiplication of new pests coming in without the natural enemies that check them in their home countries. This precarious state is unavoidable and the Territory will always need the services of trained entomologists. An account is given of some of the insect problems Hawaii has faced and the methods applied in their solution together with recommendations for the future.

Some Observations on the Fluctuations of Moisture Content in the Sugar Cane Plant:

Some evidence is offered that the moisture contents in the growing points, the leaf sheaths and the mature sticks of sugar cane may experience significant variations in moisture content from day to night, although the plant is growing in a soil adequately supplied with water. It is suggested that this effect is caused by a withdrawal of water from the plant, by transpiration, at a rate greater than the rate of supply by the roots.

It is also suggsted, although the proof is inadequate, that such diurnal fluctuations of water content may be of significance in the sugar economy of the plant. More complete studies are necessary to establish this point.

Potash Requirements for Sugar Cane:

An investigation which has had as its objective the determination of the potash requirements for optimum sugar yields as contrasted with the potash uptake by the cane plant tells a story of luxury consumption of potash, but also indicates that most of the potash which is taken up will be returned to the soil providing the cane leaves and trash are left behind in the field at harvest.

Some Considerations of the Polarographic Method of Quantitative Analysis*

By S. Okubo, C. Lyman, and L. A. Dean
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The polarographic method of quantitative analysis is attracting the attention of many analytical chemists and workers in applied fields. This is a relatively new technique applied to substances in solution, and chiefly to solutions containing the heavy metals and certain organic substances. The method is based on preparation and interpretation of current-voltage curves obtained during the electrolysis of dilute solutions containing electro-reducible or electro-oxidizable substances.

This method is especially useful for the rapid analysis of small quantities of solutions containing substances in micro-concentration; for example, one cubic centimeter of a solution containing five parts per million of zinc may be analyzed with comparative ease. Further, when the analysis has been concluded, the solution remains practically unaltered and may be used for other purposes.

This paper presents a general account of the principle, apparatus, and operating technique of the polarographic method as based upon the authors' experiences in the construction and operation of polarographs of several types. Another purpose of the paper is to acquaint readers with the possibilities and limitations of employing this method, with special reference to agricultural analyses.

Historical Review

The early and fundamental studies of the polarographic method of analysis were carried on by Heyrovský in about 1923. An empirical equation in agreement with the theory of the polarographic method was suggested by Ilkovič (4). Mac-Gillavry and Rideal (10) derived a more refined form of Ilkovič's equation which gave closer agreement between theory and practice. Heyrovský and Shikata (2) invented the polarograph, an instrument which automatically records the current-voltage curves on a moving sheet of photosensitive paper. Maas (8) and Hohn (3) worked out many of the practical applications of the polarographic technique and did much to create interest in this method in Europe. Maassen (9) applied the method to the analysis of steel, and Hamamoto (1) to organic compounds.

Little interest was shown by American scientists in polarography until quite recently. Kolthoff and Lingane (5) have made a comprehensive study of the method and have repeated and checked much of the European work. A discussion of the applications of the polarograph to organic chemistry was presented by Müller (11). Walkley (14) gives a general account of the principles, experimental technique, advantages, and limitations of the method. Stout et al. (12, 13) report procedures for determining heavy metals in plant tissue by the same method.

Operation of a Simple Apparatus

A fundamental apparatus for obtaining current-voltage curves is shown in Fig. 1. In this diagram, A is a dropping mercury cathode, B is the electrolysis cell containing the liquid to be analyzed; and C, a pool of mercury, is the anode or quiet elec-
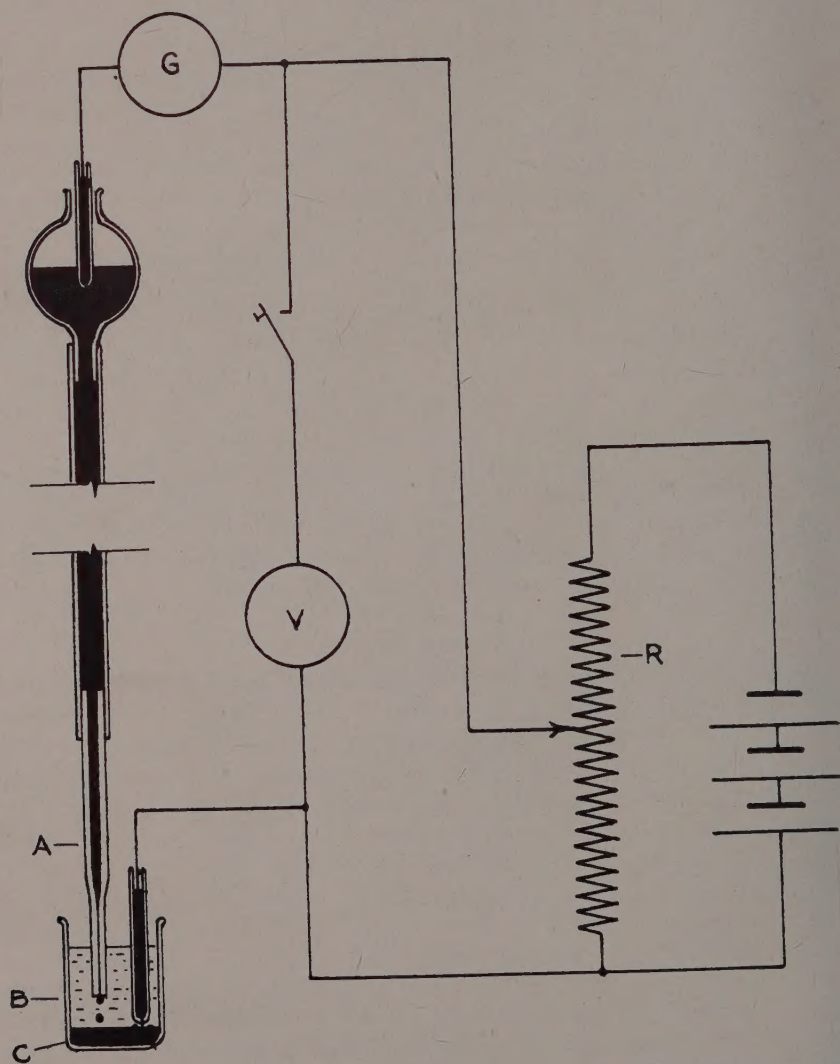

Fig. 1. Simple circuit for obtaining current-voltage curves with a dropping-mercury electrode.

trode. The galvanometer (G) which is placed in series with the cell measures the current flowing through it. This current is very small, seldom exceeding 50 microamperes. A potential varying from zero to four volts is applied across the cell by

means of the variable resistances (R), the amount being measured by the voltmeter.

The current-voltage relationship of a solution containing an electro-reducible ion is obtained by electrolyzing the solution in the cell, noting the changes in current as the voltage is increased from zero in successive steps, and graphically presenting these data.

If the dropping mercury electrode is made positive, oxidation takes place at the dropping electrode, and the waves obtained are those of the electro-oxidizable substances.

Fig. 2 shows the current-voltage curve or polarogram obtained when a 0.1 N ammonium acetate solution containing 50 p.p.m. of zinc was electrolyzed. From a study of this polarogram, it may be observed that there is only a slight slope in the portion of the curve *AB*. The current flow at the voltages corresponding to this
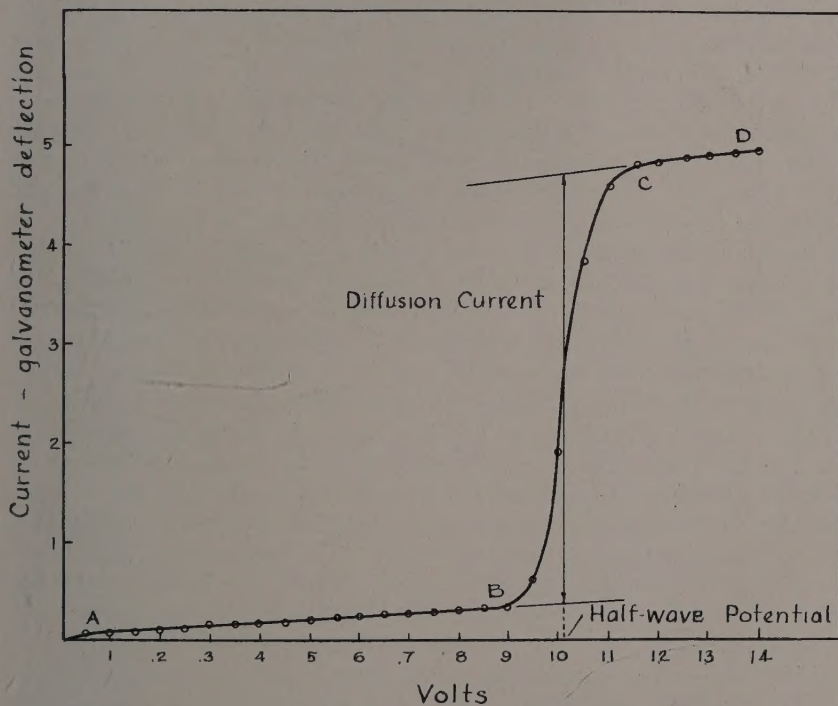
Fig. 2. Current-voltage curve of 0.1 N ammonium-acetate solution, pH 4.6, containing 50 p.p.m. of zinc.

portion of the curve is termed the *residual current*. Its amplitude may be considered as being controlled by the condenser system which embraces the dropping cathode and quiet anode and for that reason is sometimes referred to as the *condenser current*. The potential corresponding to the point B is known as the *decomposition potential* of zinc.

At this potential the zinc ions begin to deposit and amalgamate with the successive hanging mercury drops on the electrode. This causes a lowering of the concentration of zinc ions near the electrode, and a diffusion of zinc ions toward the

dropping electrode begins. As the potential is increased, the rate of deposition increases until a point is reached where the solution immediately surrounding the electrode is maintained almost completely denuded of zinc ions. Thereafter no further increase occurs in the rate of deposition since the rate of diffusion of zinc ions to the electrode under a uniform concentration gradient is the limiting factor. For this reason the current at potentials above the point where the rates of deposition and diffusion of the zinc ions become constant is termed the *limiting current* (C—D, Fig. 2).

The zinc ions are drawn to surfaces of the dropping electrode in two ways: (1) By the diffusion caused by the difference in concentration between the area immediately surrounding the electrode and the body of the solution, and (2) by electrical migration of ions due to the potential difference between the electrodes. In general it can be said that the *limiting current* is composed of two currents—the *diffusion current* and the *migration current*. Since the current through a solution of electrolytes is carried impartially by all ions present, the relative concentrations of these ions will determine to a large extent the amount of current carried by a particular kind of ion. If a large concentration of a salt is present in the solution with a reduction potential greater (more negative) than zinc, then the portion of the current carried by the zinc ions will be negligible. In such instances the *limiting current* has only one important component, the *diffusion current,* and the *limiting current* will be proportional to the concentration of zinc ions in solution. The term, *indifferent salt,* is given to a salt which is placed in the solution to eliminate the factor of the migration current. In the illustration given above (Fig. 2), ammonium acetate was the indifferent salt. Thus quantitative polarographic analysis is dependent upon controlling the conditions of electrolysis so that the limiting current or step height is directly proportional to the concentration of reducible ions in solution.

The voltage corresponding to a point midway on the polarographic wave is called the *half-wave potential.* Every reducible ion has its characteristic half-wave potential. However, this potential may be shifted by changing the pH or the electrolytes present in the solution. In an unknown solution the species of ion causing a particular polarographic wave is not always self-evident. When several electro-reducible ions are present, a current-voltage curve having several waves will be obtained and the position and height of each wave will then correspond to a particular species of ion. The simultaneous determination of several ions is possible if the half-wave potentials of the ions differ from one another by at least 0.2 volt. Otherwise an overlapping of the waves will occur making the wave-height determinations difficult and often impossible. Fig. 3 shows the polarogram of lead, copper, bismuth, and cadmium in a 5 per cent solution of sodium potassium tartrate. In this instance the waves are sufficiently separated to determine simultaneously and quantitatively the concentrations of the four significant ions present. Unfortunately ideal polarograms such as the one illustrated are almost never encountered in any practical application of the polarographic method.

TECHNICAL DETAILS OF CAPILLARIES AND ELECTROLYSIS VESSELS

Much of the successful operation of the polarographic method is dependent upon the dropping mercury electrode. The drop time of the mercury will vary with the

solution and also with the applied potential; however, with a properly functioning electrode, the weight of the drops of mercury falling per minute will remain con-
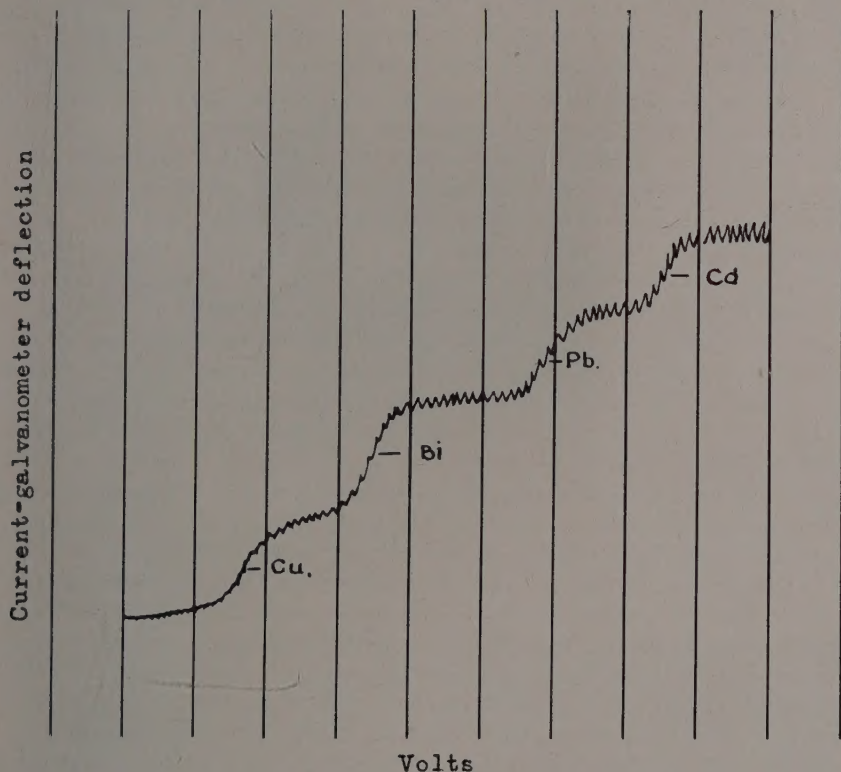
Fig. 3. Polarogram of a 5 per cent solution of potassium-sodium tartrate containing copper, bismuth, lead, and cadmium.

stant. In order for this to be true, several precautions must be taken: (1) The capillary must be dry; (2) the mercury must be pure; and (3) the capillary must be kept as free from vibrations as possible.

Experience has shown that a capillary with a drop time of from 4 to 6 seconds under a pressure of 60 centimeters of mercury is satisfactory. If the drop time is too fast, a linear relationship is not realized between the diffusion current and the concentration of the solution; if it is too slow the oscillations of the galvanometer become so large that accurate measurement of the diffusion current is difficult.

A satisfactory capillary may be made from thoroughly cleaned and dried pyrex capillary tubing having an outside diameter of 8 millimeters and a bore of 1 millimeter. The capillary is thickened in a flame to reduce the bore and then drawn out until the outside diameter is approximately 2 to 3 millimeters. Capillaries fabricated in this manner have sufficient rigidity to withstand hard usage. After the drawn capillary has been broken in the center, the drop rate may be tested by connecting the capillary to a mercury reservoir with 50 cm. of clean dry surgical rubber

tubing and placing the tip in a solution of indifferent electrolyte (0.1 N ammonium acetate or potassium chloride under a pressure of 60 cm. of mercury). If the drop time is more than 6 seconds per drop the rate can be increased by breaking off short lengths of the tip. The drop rate of the same electrode in distilled water is considerably slower than in a dilute solution of an electrolyte.

Once a satisfactory electrode has been prepared, precautions should be taken to preserve it. The diffusion current obtained by using one capillary cannot be compared with that obtained by using another, unless certain constants of both are known. Consequently it is more convenient always to use one carefully standardized capillary. Because rubber tubing connecting the capillary with the mercury reservoir necessitates frequent cleaning of the mercury and the capillary, a more desirable permanent electrode may be secured by sealing the capillary to an all-glass arrangement similar to that described by Kolthoff and Lingane (5).

When the capillary is not in use the mercury reservoir should be lowered until no drops appear, and the tip of the capillary should be immersed in either pure mercury or pure distilled water. When lowering the reservoir the tip of the capillary should remain free from a solution of electrolyte because of the danger of contamination by sucking back.

Many different types of electrolysis vessels or cells have been suggested for use in the polarographic method. The type of cell employed depends upon the amount of solution available and upon the character of the solution. If the solution need not be oxygen-free, a beaker with a pool of mercury in the bottom is satisfactory. However, dissolved oxygen interferes with many of the analyses for which the polarograph is commonly used, and in such cases the oxygen is usually removed from the solutions by bubbling hydrogen or nitrogen gas through them. Depending upon the volume of solution used, from 5 to 30 minutes are required to remove the oxygen completely. A small volume of solution will, therefore, speed up operations. Kolthoff and Laitinen (6) demonstrated that sodium sulfite would remove dissolved oxygen successfully from a potassium chloride solution.

The Polarograph

The steps previously described for obtaining polarographic current-voltage curves are slow and tedious. For this reason Heyrovský and Shikata (2) invented the polarograph, which automatically records the current-voltage curves on photographic paper. Various models of polarographs may be purchased on the market or may be constructed at small cost by laboratory staffs with shop facilities. A diagram and a photograph of the systematic arrangement of parts of the polarograph constructed in this laboratory are given in Figs. 4 and 5. The 6-inch transite drum (D), which is wound with twenty turns of No. 18 Nichrome wire, comprises the slide wire of a rotary potentiometer. This drum is rotated at a speed of about 45 seconds per revolution by an electric motor connected through a system of reduction gears. The potential, usually 2 volts, applied across the wire is controlled by the rheostat (R) and measured by the voltmeter which remains connected in the circuit. The sliding contact (F), which is connected to the anode of the electrolysis cell, impresses an increasing E.M.F. on the cell as the drum is rotated. The contact is attached to a half-nut arrangement that moves along the drum on a screw, geared
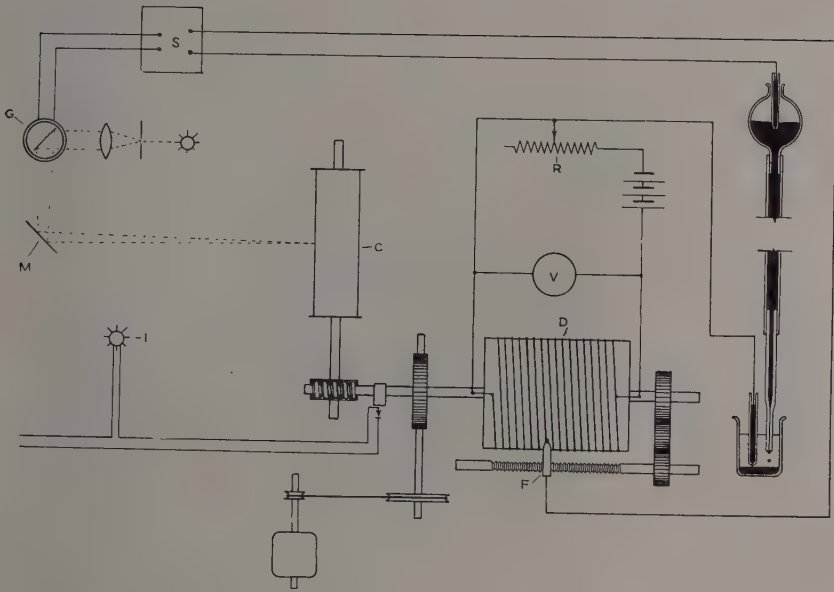
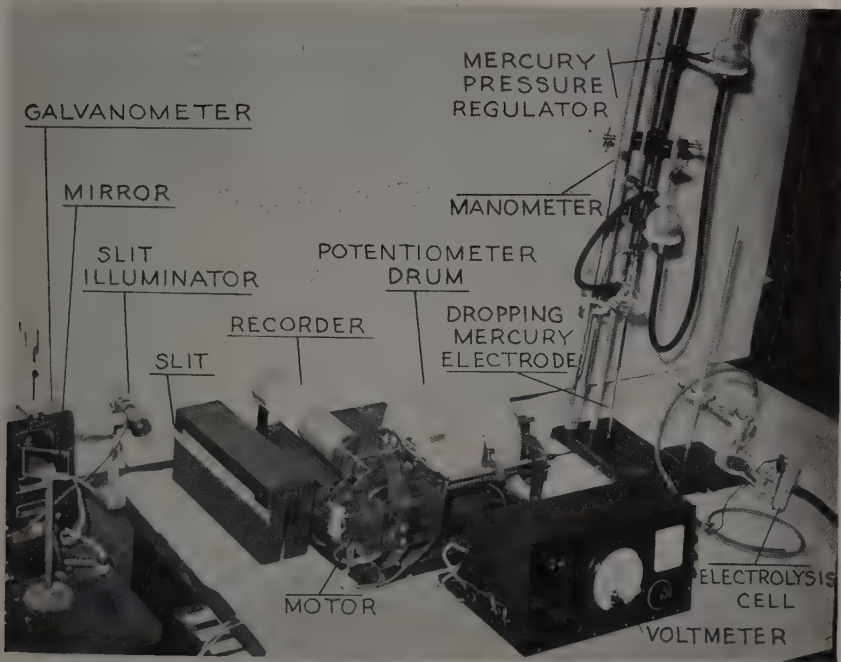Fig. 4. Systematic diagram of the polarograph constructed in this laboratory.

Fig. 5. Photograph of polarograph now in use.

to the main shaft. In this way continuous contact is maintained as the drum is rotated.

The recording cylinder (C), on which photographic paper is wrapped, is geared to the potentiometer drum in such a way that they rotate together, one revolution of the drum corresponding to a movement of one centimeter of the photographic paper. The recording cylinder is housed in a light-proof box with a narrow slit extending parallel to the axis of the cylinder. The light from the galvanometer lamp is focused on the recording cylinder. The adjusting mirror (M) adjusts the light beam without disturbing the galvanometer (G). The slit illuminator (I), connected to a switch operated by a cam on the shaft of the potentiometer drum, causes a light to flash on the slit once each revolution of the drum. Thus thin lines are automatically printed on the paper, marking off equal increments of applied voltage. For example, if 2 volts are applied across the slide wire then each turn of the drum will give an increase of one-tenth volt and the recording paper will be lined in one-tenth volt increments. The Ayrton type of shunt (S), connected in parallel with the galvanometer, governs the fraction of the total current that passes through it, thus controlling the amount of deflection.

The polarograph has several advantages over manual measurement. The actual time involved in getting a polarogram is much less. Several curves can be recorded on the same paper. The record is continuous rather than a series of points so that discontinuities or irregularities are recorded that might be overlooked in the manual method. The records are permanent and can easily be filed away for future reference.

However, a polarograph is not essential to polarographic research and analyses. Much of the theoretical work, in which very sensitive current- and voltage-measuring instruments are required, may be obtained more easily by the manual method.

Analytical Application of the Polarographic Method

The polarographic method for quantitative analysis is of importance chiefly because small quantities of very dilute solutions can be handled. Solutions with concentrations from 10^{-3} to 10^{-5} molar are most conveniently adaptable. However, the method has not as yet been perfected for routine examination of unknown mixtures of substances; consequently it cannot replace the spectrograph. Our experience has shown that at least a year's experience is required for an operator to become proficient in the use of the polarographic method.

Operation of the instrument itself is not difficult, for the procedure is actually simple and rapid. However, care and experience are required in devising methods for preparing satisfactory solutions of the substances to be analyzed. One of the common difficulties encountered is the presence of a large concentration of ions which have a decomposition potential lower (less negative) than that of the ions to be determined. For example, determining the amount of lead in a zinc compound is quite simple, the decomposition potential for lead being about −0.5 volt and for zinc about −1.0 volt. However, it would be impossible to determine the amount of zinc in a lead compound without first removing most of the lead by a standard chemical separation. The compensation method, which reduces the diffusion current of an interfering ion, has been suggested by Lingane and Kerlinger (7) and

by others. This compensation is accomplished by sending a current, from an out-side source, equal in magnitude to the interfering diffusion current, through the galvanometer in the opposite direction.

Another difficulty commonly encountered is the presence of ions with a de-composition potential close to that of the ions to be determined. In such a case, an overlapping of waves occurs which must be resolved before measurements can be obtained. Many ingenious devices have been suggested for separating over-lapping waves. For example, Stout et al. (12) have shown that the waves for nickel and zinc can be successfully separated by adding potassium thiocyanate.

In general it may be said that for any type of substance which is to be deter-mined by polarography, it is necessary first to perfect a method of preparing a suitable solution of the substance; usually by trial and error.

The practical application of the polarographic method is well demonstrated by determinations made in this laboratory of the amounts of zinc in various samples of perchloric acids, prior to employing perchloric acid to wet-ash samples of plant material for zinc determinations. Five cc. aliquots of the perchloric acids were evaporated to dryness in 30 cc. pyrex beakers and the residue treated with 2 N hydrochloric acid and evaporated to dryness twice. Each residue was then dissolved in 2 cc. of a solution, adjusted to pH 4.6, which was 0.1 N in respect to ammonium acetate and 0.025 N in respect to potassium thiocyanate. The current-voltage curves or polarograms for the solutions prepared as above are given in Fig. 6. An evaluation of the heights of the polarographic waves for zinc showed the perchloric acid samples 1–5 to contain 0.19, 0.22, 0.19, 0.21, and 3.0 p.p.m. of zinc respec-tively. The perchloric acid in sample 5 was a technical grade, and a higher shunt ratio was used in obtaining the polarogram.
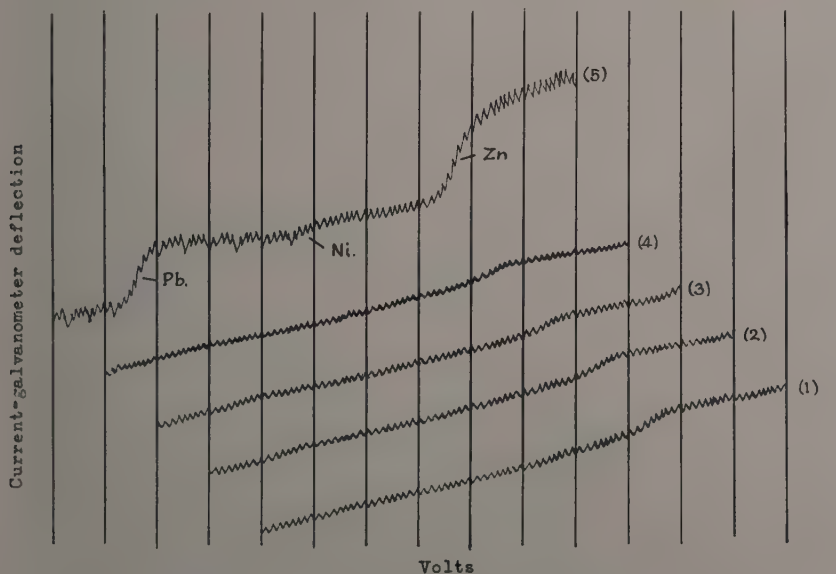
Fig. 6. Polarograms of zinc determination in samples of perchloric acids.

There are numerous acceptable procedures for establishing the relationship between the measured step height or diffusion current and the concentration of the solution electrolyzed. When a large number of determinations are being made a
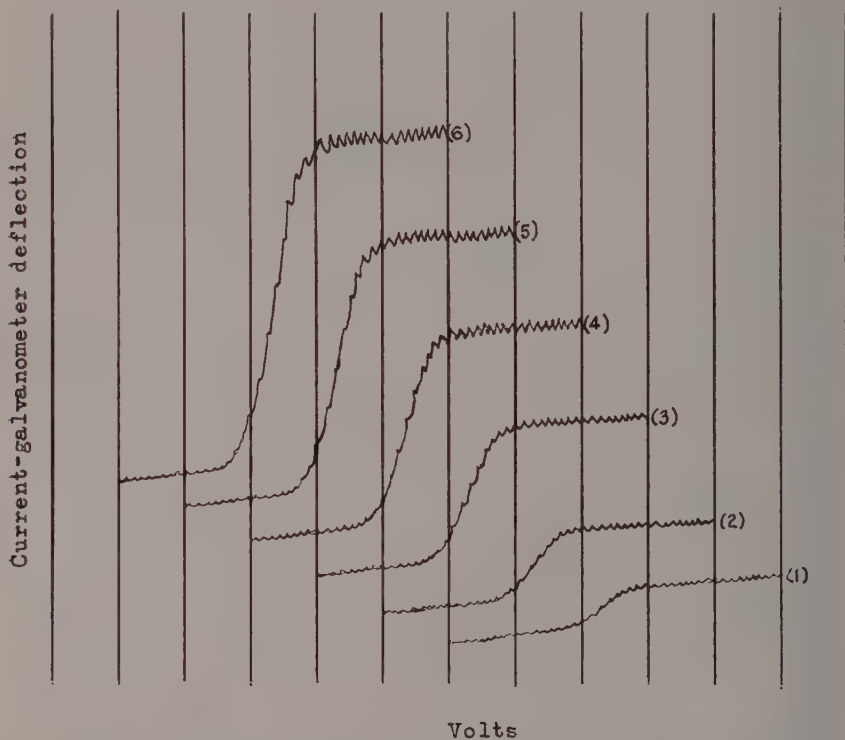
Fig. 7. Polarographic waves measured for a zinc standardization curve.

standardization curve is convenient. The measured heights of the polarographic waves shown in Fig. 7 were plotted to obtain such a curve for zinc. The solutions were prepared by evaporating suitable aliquots of a standard zinc chloride solution to dryness and dissolving the residue in 5.00 cc. of a 0.1 N ammonium acetate solution which was 0.025 N in respect to potassium thiocyanate and adjusted to pH 4.6. When the step heights were plotted against the concentrations of the solution the standardization curve (Fig. 8) was obtained. The tangent of this line was calculated by the method of least squares and found to be 0.255. This tangent value was used for calculating the concentrations of unknown solution in preference to obtaining the value from a direct reading on the standardization curve. This method is only applicable when the drop time and the temperature are rigidly controlled. It is also possible to use an addition method, that is, after a polarogram of an unknown solution has been prepared a known amount of the ion to be determined is added to the unknown solution and another polarogram prepared. From the increase in height resulting from the known addition the original concentration of the unknown may be calculated.
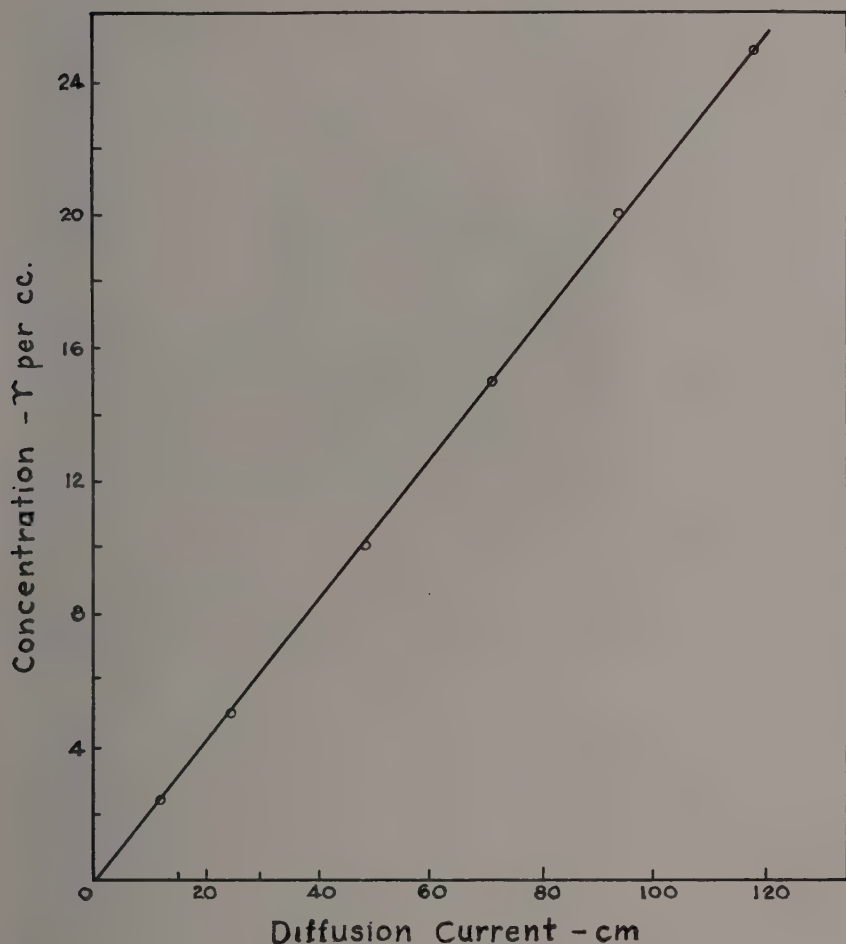
Fig. 8. Standardization curve for zinc in a 0.1 N ammonium-acetate and 0.025 N potassium-thiocyanate solution, adjusted to pH 4.6.

SUMMARY

1. A brief account of the history, principles, and operation of the polarographic method of analysis has been presented.

2. A description of the construction and operation of a polarograph is given.

3. Possible analytical applications and limitations of the polarographic method are illustrated and discussed.

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Varietal Differences of Sugar Cane in Growth, Yields, and Tolerance to Nutrient Deficiencies

By J. P. MARTIN

It has been known for many years that the ten elements, carbon (C), oxygen (O), hydrogen (H), nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), sulphur (S), and iron (Fe) are indispensable for normal plant growth, and more recently manganese (Mn), zinc (Zn), boron (B), copper (Cu), silicon (Si), and a few other elements have been added to this list. Inasmuch as many compounds of these elements occur in the soil, it is extremely difficult to determine the soil's exact chemical composition. Nutritive substances applied to the soil as fertilizers contribute toward increased crop yields; the optimum amounts of these materials to be applied are often determined by chemical analyses of the soil and by pot and field experiments.

The chemical composition of plants varies greatly, depending largely on environmental conditions under which they are grown and their age; differences, of a smaller magnitude, occur within varieties of a given species. The rate of absorption of the mineral elements by plants changes with their different stages of growth.

The nutritional requirements of plants are frequently studied in water or sand cultures. The preparation of the solutions with distilled water and chemically pure salts makes it possible to study the behavior of the plants under controlled conditions. For the past ten years considerable research work has been conducted at this Station on the nutrition of the sugar cane plant in water and sand cultures. Most of these studies have had to do with inducing and studying deficiency symptoms of specific elements on a number of the commercial cane varieties; to a much lesser degree the effects of excesses of certain elements have been investigated. To date it has been definitely shown that the following elements are essential for satisfactory cane growth in culture solutions: N, P, K, Ca, Mg, S, Fe, Mn, and B. Insufficient work has been carried out with copper, zinc, and silicon to comment on their indispensability to the growth of sugar cane. Under field conditions we have observed deficiency symptoms of the following elements only: N, P, K, Mg, Fe, and Mn.

A knowledge of the nutrient requirements of a cane variety is of the greatest importance in securing a maximum growth in terms of productiveness. It has often been demonstrated that varieties respond differently to differential fertilization and this is also true for a single variety.

The primary purpose of this paper is to record growth and yield differences of H 109, 31–2806, 32–1063, and 32–8560 when grown in a complete nutrient solution and in solutions lacking nitrogen, phosphorus, potassium, calcium, magnesium, sulphur, iron, manganese, and boron respectively. In order that all varieties within a deficiency series would receive the same treatment, one plant of each variety was grown in the same container for each series. Marked growth differences soon be-

came apparent in the varieties and it was evident that some varieties were much more tolerant than others to the various nutrient deficiencies.

Experimental Procedure

During May 1940 an equal number of cuttings of H 109, 31–2806, 32–1063, and 32–8560 were planted in black sand and irrigated with tap water; eight weeks later shoots of uniform size of each variety were removed from the original cuttings and placed in a complete, aerated, nutrient solution. The plants were grown for a period of six weeks in this solution during which time all plants made what appeared to be a normal growth. On August 12, 1940, plants of uniform size, health and vigor of each variety were again selected and one plant of each of the four varieties was placed in each of ten 4-gallon earthenware containers with glazed inner surfaces. In one series the plants received the standard nutrient solution while in the other nine series the plants were grown in nutrient solutions lacking each of the following elements: nitrogen, phosphorus, potassium, calcium, magnesium, sulphur, iron, manganese and boron. With this arrangement each plant of each variety received the same treatment in the various series.

The culture solutions used throughout the experiment for the control and deficiency series were prepared with distilled water and chemically pure salts, thus making it possible to study the reaction of the plants in media of a known chemical composition. The pH value of all series was adjusted to 5.2 at the time the solutions were prepared; however, the pH values of the solutions changed somewhat by the time the solutions were renewed which was every 7 to 10 days. All solutions were aerated continuously. The complete and the deficient nutrient solutions were prepared the same as those used in 1933 and 1934 by Martin (1, 2), wherein nutritional deficiency symptoms of H 109, POJ 2878, Badila, Yellow Caledonia and POJ 36 were recorded.

The arrangement of the four varieties in each container was identical; for example, as shown in Fig. 2, the variety H 109 was placed in front and left, 31–2806 in front and right, while 32–1063 was placed in back and left, and 32–8560 in back and right. The reader is asked to bear this arrangement of the plants in mind when referring to Figs. 1, 3, and 4 since the individual plants therein are not labelled.

Inasmuch as the test was designed to study the leaf and stalk development of the varieties in relation to the deficiency of each of the nine elements, no attempt was made to study root development. A study of the latter would involve growing each variety in individual containers. Since the deficiency symptoms of the elements under study in this experiment have been previously described in detail (1, 2) they will not be so treated in this article.

All series were photographed on December 10, 1940, and it will be noted in Figs. 1, 3, and 4 that the plants in the control series appear with each group of the deficiency series; with this grouping it is easier to compare the plants in each deficiency series with those in the control series. The variety 31–2806 in each series, after being photographed with the other varieties, was given to Dr. H. Clements of the University of Hawaii for chemical analyses, the results of which will be made available by him at a later date; hence no data on 31–2806 appear in Tables I or II.

Discussion of Results

On February 14, 1941, or 6 months after the plants were placed in the deficiency series, Brix readings were recorded from the upper, middle, and lower portion of each stalk of H 109, 32–1063 and 32–8560 in each series. These data presented in Table I were obtained with the hand punch and hand refractometer. It will be noted that the average Brix of the upper, middle, and lower portion of each stalk (Table I) is in most instances somewhat higher than the Brix for the same variety and treatment in Table II.

The experiment was harvested February 18, 1941, with the assistance of L. R. Smith of the Agricultural department, and the results are given in Table II. Each stalk was weighed and the juice of the entire stalk of each variety was expressed in the small "Cuba A Mill" and the yield figures in the table are based on the expressed juice. The Brix readings were determined by means of the polariscope. Three stalks of cane per foot of line or 30,000 stalks per acre were used as the basis for estimating the tons cane per acre (TCPA), tons sugar per acre (TSPA) and the tons sugar per acre per month (TSAM) as given in Table II.

The two graphs in Fig. 5 show the cane and sugar yields at harvest from H 109, 32–1063 and 32–8560 (age nine months) in the control and deficiency series. It will be noted that a close correlation occurs between the cane and sugar yields for each variety and that the effects of the deficiencies were more marked on the sugar than on the cane yields.

TABLE I

BRIX READINGS OF H 109, 32–1063, AND 32–8560 IN THE CONTROL AND DEFICIENCY SERIES AS DETERMINED BY THE HAND REFRACTOMETER

		Com.	—N	—P	—K	—Ca	—Mg	—S	—Fe	—Mn	—B
H 109	U*	19.4	13.2	11.8	7.4		7.6	17.0	14.2	17.6	11.6
	M*	22.2	16.4	20.8	13.6	16.0	5.6	19.5	15.0	21.8	21.2
	L*	18.8	17.5	20.4	13.0		6.6	18.4	15.0	18.4	17.2
Average		20.1	15.7	17.7	11.3		6.6	18.3	14.7	19.3	16.7
32–1063	U	21.5	19.4	18.2	8.0		11.4	20.8	23.0	22.2	22.0
	M	23.6	21.6	22.8	11.4	17.0	12.2	21.6	24.8	23.2	22.2
	L	23.4	22.2	23.0	13.2		13.6	20.4	23.4	23.0	21.4
Average		22.8	21.1	21.3	10.9		12.4	20.9	23.7	22.8	21.9
32–8560	U	22.6	19.3	18.8	20.8		15.4	22.4	21.4	22.4	23.0
	M	24.6	22.7	22.0	23.0	22.0	17.6	22.6	22.8	23.2	22.4
	L	22.8	22.8	22.0	21.4		13.4	22.8	23.2	22.0	21.4
Average		23.3	21.6	20.9	21.7		15.5	22.6	22.5	22.5	22.3

* U. M. L, = upper, middle, and lower portion of stalk.

TABLE II

COMPARATIVE YIELDS OF H 109, 32–1063, AND 32–8560 WHEN GROWN IN
A COMPLETE NUTRIENT SOLUTION AND IN SOLUTIONS LACKING EACH
OF THE FOLLOWING ELEMENTS: N, P, K, Ca, Mg, S, Fe, Mn, and B

Deficiency series	Variety	Harvesting results of deficiency series					Yields per acre*		
		Wt. per stalk lbs.	Brix	Purity	Q. R.	Sugar per stalk lbs.	TCPA (9 mos.)	TSPA (9 mos.)	TSAM
Control	H 109	3.20	19.0	89.5	7.7	.42	48	6.2	.69
(Complete	32–1063	3.75	21.6	86.6	7.2	.52	56.25	7.8	.87
Nut. Soln.)	32–8560	4.50	21.8	89.0	6.8	.66	67.5	9.9	1.10
	H 109	0.30	17.4	86.2	9.0	.03	4.5	.5	.06
Nitrogen	32–1063	1.75	19.2	89.1	7.7	.23	26.25	3.4	.38
	32–8560	1.30	20.1	90.0	7.2	.18	19.5	2.7	.30
	H 109	2.00	17.5	84.6	9.2	.22	30.0	3.3	.37
Phosphorus	32–1063	2.25	19.2	84.4	8.4	.27	33.75	4.0	.44
	32–8560	3.00	19.5	85.1	8.2	.37	45.00	5.5	.61
	H 109	1.10	12.8	75.0	15.6	.07	16.5	1.1	.12
Potassium	32–1063	2.10	12.2	68.9	19.2	.11	31.5	1.6	.18
	32–8560	3.20	19.7	87.8	7.7	.42	48.0	6.2	.69
Calcium	H 109								
	32–1063	The growing point of each plant was dead at harvest.							
	32–8560								
	H 109	0.60	7.5	57.3	46.8	.01	9.0	.2	.02
Magnesium	32–1063	1.90	11.8	79.7	15.1	.13	28.5	1.9	.21
	32–8560	1.90	15.8	81.0	11.0	.17	28.5	2.6	.29
	H 109	1.40	16.5	86.1	9.5	.15	21.0	2.2	.24
Sulphur	32–1063	2.00	19.4	83.0	8.6	.23	30.0	3.5	.39
	32–8560	2.50	20.9	86.1	7.5	.33	37.5	5.0	.56
	H 109	1.20	14.6	77.4	12.9	.09	18.0	1.4	.16
Iron	32–1063	1.40	22.4	84.4	7.2	.19	21.0	2.9	.32
	32–8560	2.00	21.6	88.0	7.0	.29	30.0	4.3	.48
	H 109	2.25	18.5	90.3	7.8	.29	33.75	4.3	.48
Manganese	32–1063	3.75	20.4	87.3	7.5	.50	56.25	7.5	.83
	32–8560	3.40	20.6	88.8	7.2	.47	51.00	7.1	.79
	H 109	4.00	17.9	89.3	8.2	.49	60.00	7.3	.81
Boron	32–1063	2.30	19.8	87.9	7.7	.30	34.50	4.5	.50
	32–8560	2.20	21.7	87.6	7.0	.31	33.00	4.7	.52

* Based on 3 stalks per foot of line or 30,000 stalks per acre.

Control Series: The control plants which received the complete nutrient solu-
tion throughout the experiment made a uniform rate of growth at all times. The
color of the leaves was normal, and the stalk diameters and lengths (best shown in
Fig. 2, pot No. P 10) compared favorably with those of field cane. The growth of
the four varieties in this series may be compared with that of the same varieties in
the nine deficiency series in Figs. 1, 2, 3, and 4. The varieties 32–1063 and 32–8560
produced the best growth, the millable cane of each stalk at harvest being slightly
over six feet in length. The growth of H 109 and 31–2806 was approximately
equal, but was less for each variety than that of 32–1063 or 32–8560; this is again

Fig. 1. The upper photograph shows the growth of H 109, 31–2806, 32–1063 and 32–8560 in the complete, minus-nitrogen, minus-phosphorus, and minus-potassium series; the lower photograph shows, in greater detail, stalk differences of each variety in the four series.

shown by the weight of each stalk in Table II—H 109 weighed 3.2 pounds, 32–1063 weighed 3.75 pounds while 32–8560 weighed 4.5 pounds. When expressed in yields per acre all varieties showed an excellent performance—the tons of sugar per acre per month for H 109, 32–1063, and 32–8560 being .69, .87 and 1.10 respectively.

At the age of 9 months the three varieties were found to have excellent juice qualities (Table II). It is of interest to note in Table I that the middle portion of each stalk had the highest Brix and this was the case in several of the other series. It is of further interest to note the high sucrose content of the control plants especially since they were grown in water cultures and since nitrogen was supplied in the culture solution at the rate of 126 parts per million (378 pounds per acre) every 7 to 10 days. At no time was water or nitrogen a limiting growth factor. From the standpoint of yields 32–8560 was without question much superior to 32–1063 or H 109; the variety 32–1063 proved to be second best.

Minus-nitrogen Series: The first symptoms of nitrogen deficiency appeared eight days after nitrogen had been omitted from the solution and thereafter the leaf and stalk symptoms became more acute. The growth of each variety was greatly retarded, as shown in Figs. 1 and 2, pot No. 11; however, it was extremely interesting to observe the superior growth of 32–1063 and 32–8560 to that of H 109 and 31–2806. These differences are best shown in Fig. 2 wherein the label of each variety points to the division between the green- and dry-leaf portion of the stalk.

The weight per stalk of each variety was far less than in the control series and marked differences resulted among the varieties within the series; the weight expressed in pounds per stalk being .30 for H 109, 1.75 for 32–1063 and 1.30 for 32–8560 (Table II). Of the three varieties 32–8560 had the best juice, followed by 32–1063 and H 109.

The very low yields in this series can be directly attributed to the lack of nitrogen. Two hypotheses are suggested to explain the superior growth of 32–1063 and 32–8560 to that of H 109 and 31–2806: (1) 32–1063 and 32–8560 each absorbed more nitrogen than either H 109 or 31-2806 while they were growing in the complete nutrient solution, or (2) 32–1063 and 32–8560 are more efficient in their utilization of nitrogen than H 109 and 31–2806.

Minus-phosphorus Series: The growth (in terms of length) of all varieties in this series was approximately the same (Fig. 1, pot No. P 12), but stalk lengths and stalk diameters were considerably less than in the control series. The leaves were not as dark a green and were somewhat narrower than those on the control plants. The older leaves manifested a premature yellowing, drying and dying at the tips. At no time in our nutritional studies have phosphorus deficiency symptoms been as definite as the deficiency symptoms of the other elements which have been studied.

As shown in Table II the variety 32–8560 had the greatest weight per stalk, the best juice and the greatest yields per acre, while the variety 32–1063 was second in these respects. It is shown in this experiment that a deficiency of phosphorus reduced the juice quality and cane yields of each variety.

Minus-potassium Series: One month after the element potassium was omitted from the solution definite leaf deficiency symptoms were observed. Later a retardation of growth, a yellowing and spotting of the older leaves, a premature drying and dying from the tips of the older leaves, and a reddish discoloration of the upper surfaces of the midribs were present. Of the four varieties, H 109 manifested the most acute symptoms, with 31–2806 next. The growth of 32–8560 was much superior to that of 32–1063 and the leaf symptoms of potassium deficiency were less

severe; the growth of these two varieties was much superior to that of H 109 and 31–2806 (Fig. 1, pot No. P 13).

The variety 32–8560 proved to be outstanding in this series, it having the best juice and producing by far the greatest cane and sugar yields (Table II). The
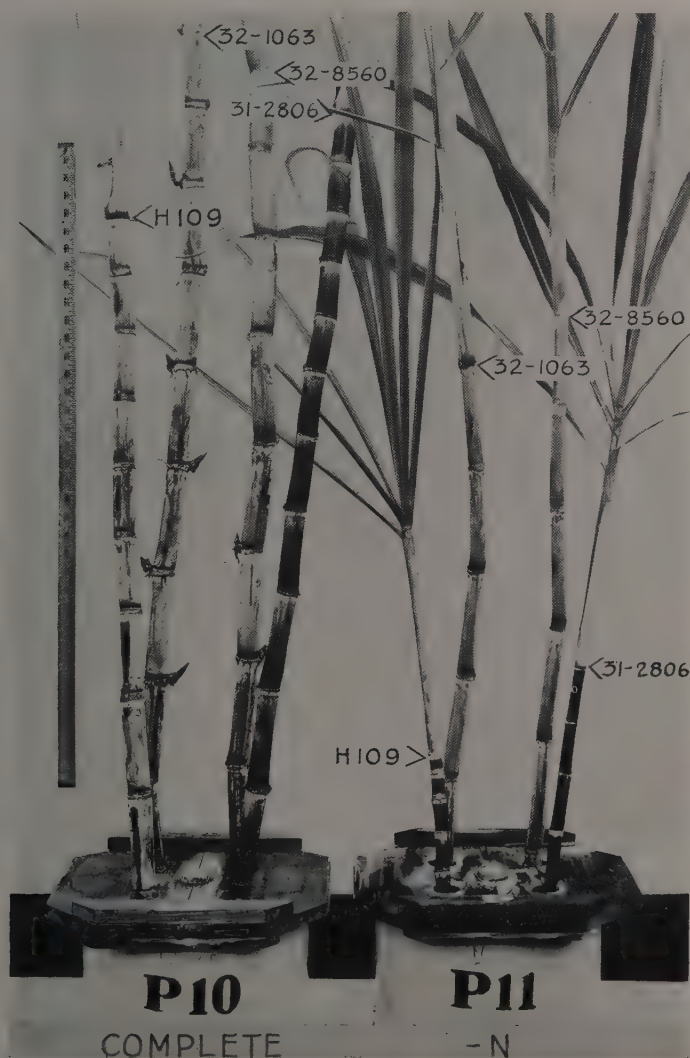
Fig. 2. Note the marked differences in growth and stalk diameter of the plants in the minus-nitrogen series (right) from those of the plants in the complete nutrient solution (left). The label of each variety indicates the division of the green- and dry-leaf portion of the stalk. The arrangement of the varieties in Figs. 1, 3, and 4 is identical to that in this figure: H 109 front and left, 31–2806 front and right, 32–1063 rear and left, and 32–8560 rear and right.

variety 32–1063 produced more cane than H 109 but had poorer juices, although the sugar yields of 32–1063 were slightly higher than H 109.

The results from this deficiency series indicate that the variety 32–8560 would be a much superior cane to grow in soils deficient in potash than either 32–1063 or
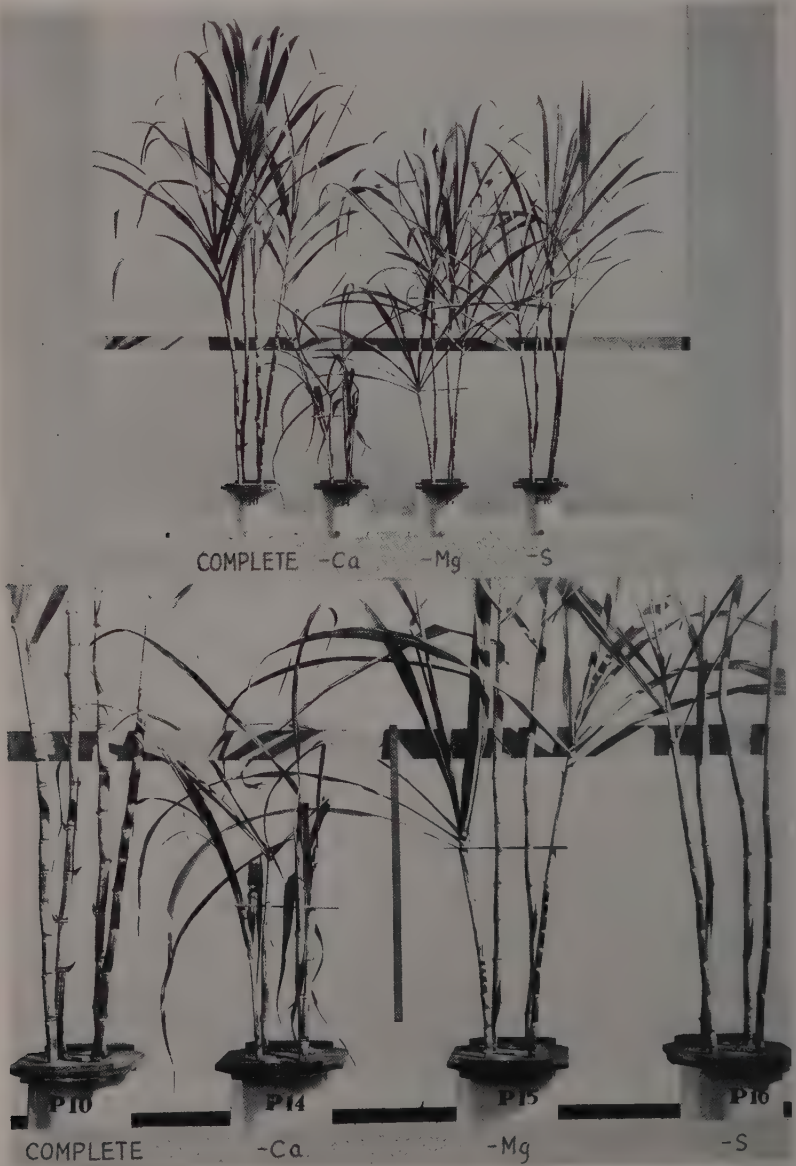
Fig. 3. Showing total growth and stalk differences of each of the four varieties in the minus-calcium, minus-magnesium, and minus-sulphur series. The growth of the control plants is shown on the left.

H 109. It is apparent that 32–8560 is much more tolerant to potash deficiency than 32–1063 or H 109.

Minus-calcium Series: At the end of four weeks clear-cut calcium deficiency symptoms, as characterized by a chlorotic condition of the leaves, a spotting on the older leaves and a retardation of growth, were apparent. These symptoms soon became more acute, the youngest leaves were extremely weak and made no further growth, and the spindle of each plant died. The growth of the plants four months after they were deprived of calcium is shown in Fig. 3, pot No. P 14 together with the growth of the control plants (pot No. P 10).

Inasmuch as the growing point of each variety had died and the plants had made little or no growth, no attempt was made to harvest the plants in this series.

Minus-magnesium Series: It will be noted in Fig. 3, pot No. 15 that the growth of all plants was greatly depressed in the absence of magnesium and that the stalk size was less than that of the control plants. The first leaf symptoms of magnesium deficiency were observed 22 days after this element was omitted from the solution. The variety H 109 produced the least amount of growth and manifested the most acute leaf symptoms, while 31–2806 was slightly less affected in these respects. The growth of 32–1063 and 32–8560 was about equal, and was much superior to that of H 109 and 31–2806. The deficiency symptoms on 32–1063 and 32–8560 were less pronounced than on the other two varieties.

A deficiency of magnesium had a very detrimental effect on the juices and cane and sugar yields of all varieties, as noted in Table II; the variety H 109 was most affected, with 32–1063 next while 32–8560 was least affected. Similar results have been observed in other experiments.

An application of magnesium to the soil, in the form of magnesium sulphate, might improve the juice quality of a variety where poor juices are experienced in soils which are deficient in magnesium.

Minus-sulphur Series: The effects on the plants subsequent to the removal of sulphur from the solution were quite similar to those when nitrogen is omitted. A paling of the young leaves was noted at the end of three weeks and as the experiment continued all leaves developed a light lemon-yellow color (quite similar to nitrogen deficiency) and growth was retarded (Fig. 3, pot No. P 16). Of the four varieties in this series the variety H 109 made the least amount of growth, while the growth of the other three varieties was quite uniform. The growth of all varieties was considerably less than in the control series. As shown in Table II a deficiency of sulphur resulted in poorer juices and lower cane and sugar yields.

Sulphur plays a very important part in the plant's metabolism, especially in the formation of proteins which in turn enter into the making of protoplasm; thus a retardation of growth results with a sulphur deficiency. To date sulphur deficiency symptoms have not been recorded on field cane.

Minus-iron Series: Twelve days after this series had been underway iron deficiency symptoms, recognized by a pale striping on the young leaves, appeared on 32–1063 and 32–8560. At the end of 6 to 8 weeks the leaf symptoms on all plants were very conspicuous, the younger leaves were entirely white and the plants were greatly depressed in growth (Fig. 4, pot No. P 17). The varieties 32–1063 and 32–8560 made the best growth, with H 109 next best, while 31–2806 produced the

smallest amount of growth. There was a sharp contrast between the iron-deficient plants and those in the control series both in color and growth.

An absence of iron had little effect on the juice quality of 32–1063 or 32–8560 but it was responsible for poor juices in H 109 (Table II). The cane weight of
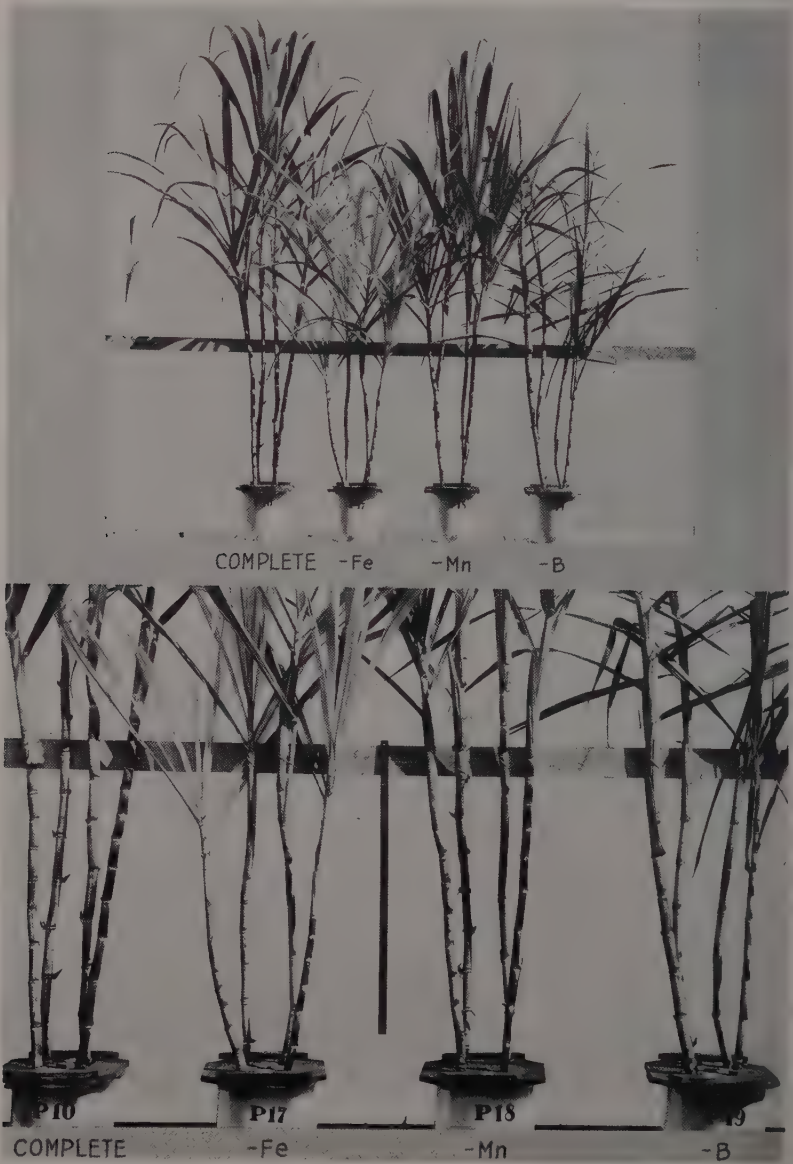

Fig. 4. Showing the effects of iron, manganese, and boron deficiencies on the growth of H 109, 31–2806, 32–1063, and 32–8560. The control plants are on the left.

CANE AND SUGAR YIELDS IN THE CONTROL AND DEFICIENCY SERIES
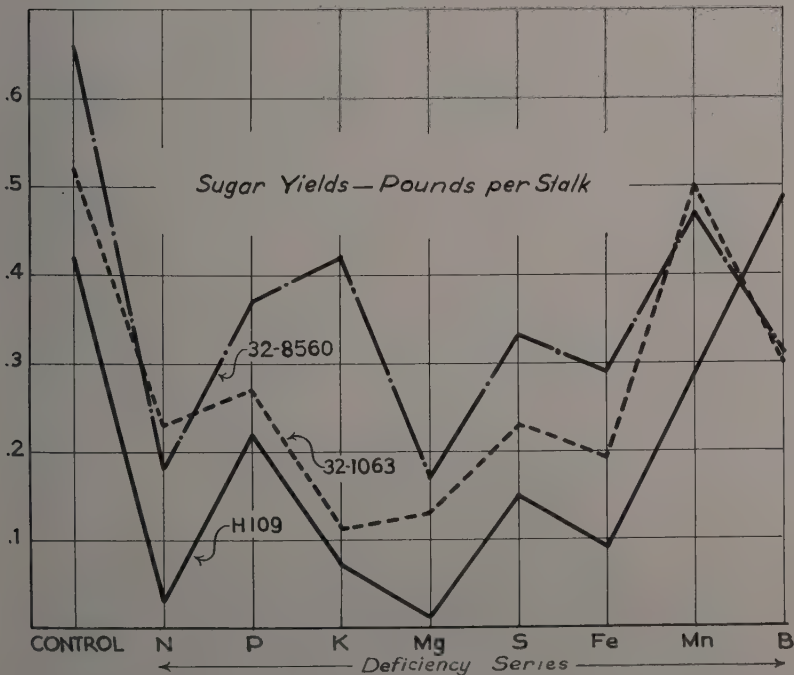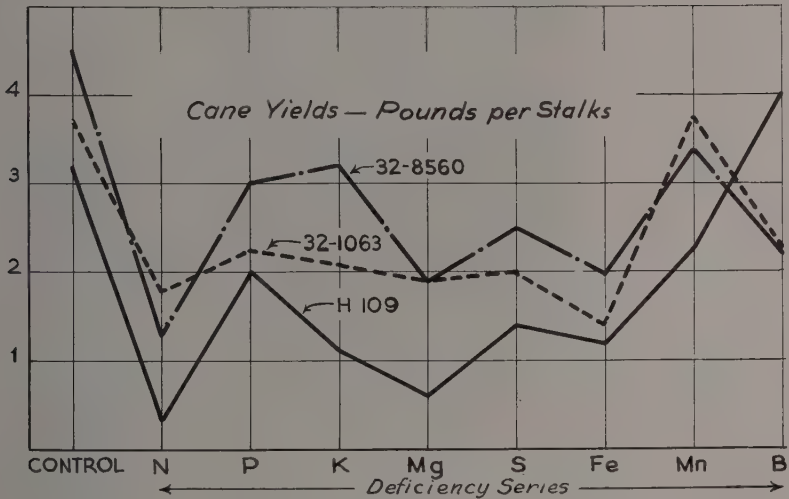## (H 109, 32-1063, 32-8560)

Fig. 5. Comparative cane and sugar yields of H 109, 32–1063, and 32–8560 in the complete and deficiency series.

each of the three varieties was markedly reduced thus accounting for the low sugar yields when compared with those of the control plants.

With a reduction of chlorophyll the process of photosynthesis—a putting together of raw materials by light energy to form carbohydrates—is greatly retarded. It has been shown that iron does not enter into the composition of chlorophyll but that it is necessary for the normal growth of all plants. The immobility of iron within plants has been demonstrated a number of times; for example: when new cane leaves develop on plants in nutrient solutions lacking iron they soon become chlorotic if iron is not returned to the solutions.

Minus-manganese Series: Very few leaf symptoms of manganese deficiency developed on any of the plants and, as shown in Fig. 4, pot No. P 18, the growth of the plants was almost equal to that of the control plants. Toward the end of the experiment the alternating dark green and light green leaf stripes typical of manganese deficiency had developed.

In previous studies symptoms of manganese deficiency were not detected until after 2 months or more. Only extremely small quantities of manganese (.25 of a part per million which is equivalent to approximately .75 of a pound per acre) are essential for normal cane growth in nutrient solutions. The slightest trace of this element from any source would prevent the development of the symptoms.

Even though small differences were noted in total length of growth, a noticeable reduction in cane weight for each variety was apparent and the juice quality was lower, both of which accounted for the lower cane and sugar yields than in the control series (Table II). Of the three varieties in this series 32–1063 was the most tolerant to manganese deficiency.

Minus-boron Series: A conspicuous reduction in growth of each variety and definite leaf symptoms of boron deficiency were noted. It was very interesting to observe the superior growth of H 109 to that of 31–2806, 32–1063 and 32–8560 (Fig. 4, pot No. P 19); it is possible that H 109 either took up more boron while in the complete nutrient solution or that it has a much higher tolerance to a lack of boron than the other three varieties.

The first leaf symptoms appeared 12 days after boron was omitted from the solution and their development thereafter was identical to those described in 1934 on H 109, POJ 36, POJ 2878, Yellow Caledonia and Badila by Martin (2).

The abnormal growth of all varieties was characterized by depressed growth, especially in the growing-point region, and the development of distorted leaves with definite chlorotic leaf markings. At the end of 4 months the young leaves of 31–2806, 32–1063 and 32–8560 were badly distorted and exhibited symptoms similar to those of pokkah boeng disease which is caused by the fungus *Gibberella Fujikuroi* (Saw.) Wr. (*Fusarium moniliforme* Sheldon).

The harvest data, Table II, show that H 109 produced more cane and sugar but had a slightly lower juice quality than the other two varieties and also lower than it had in the control series. Both 32–1063 and 32–8560 produced considerably less cane and sugar than in the control series. The variety H 109 was much more tolerant to boron deficiency than 32–1063 or 32–8560. This is the only series wherein H 109 was superior in cane and sugar yields to the other two varieties.

Summary

From the foregoing results we may conclude that:

1. Normal growth, and cane and sugar yields of each variety were depressed when any one of the nine elements was omitted from the solution.

2. Typical deficiency symptoms of each element developed on all varieties, but it was clearly demonstrated that some varieties manifested a much higher degree of tolerance to certain deficiencies than others.

3. The juice quality of all varieties was definitely affected when certain elements were omitted from the nutrient solution, and the effect on some varieties was more marked than on others.

4. Varieties have different nutritional requirements.

5. The juice quality of a variety under field conditions may be improved in specific areas by applying certain elements to the soil.

Literature Cited

(1) Martin, J. P., 1934. Symptoms of malnutrition manifested by the sugar cane plant when grown in culture solutions from which certain essential elements are omitted. The Hawaiian Planters' Record, 38: 3–31.

(2) ————, 1934. Boron deficiency symptoms in sugar cane. The Hawaiian Planters' Record, 38: 95–107.

Sorption* of Potassium and Ammonium by Hawaiian Soils

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Wherever rainfall or irrigation water penetrates the soil to depths below the root zone, there is a possibility of loss of plant nutrients by leaching. In the absence of a fluctuating water table, the leached nutrients are not recoverable by the crop.

The ability of soils to prevent loss by leaching varies extremely. It is common knowledge that when soluble phosphates are applied to Hawaiian soils, the phosphate constituent of the fertilizer unites with the soil to such a degree that losses of this nutrient by leaching are wholly negligible. Furthermore, much of the phosphate thus fixed is so insoluble that it is not readily available to plants. At the other extreme are the nitrates. The soil does not possess the ability to unite with nitrogen in this form, and hence nitrates are very susceptible to leaching.

Under some conditions soils are known to combine with certain of the bases‡ commonly introduced as fertilizers. Under other circumstances they apparently do not. Hance and coworkers (6) studied the effect of high-potassium irrigation water (25 p.p.m. K_2O) on the amount of potassium in certain soils of the Hawaiian Commercial and Sugar Co., Ltd. Although several hundred pounds of potassium per acre had been applied annually over a period of years, the soil retained none of it. Enormous amounts of sodium chloride had been similarly applied to this area, yet examination of the soil profile to a depth of 5 feet failed to reveal amounts of this salt which were greater than those in adjacent virgin areas, which had never received irrigation water. Further evidence that under some circumstances the soil does not react with and hold sodium is to be found in a consideration of the quantities of this base which are present in rain water. Collins and Williams (3) found that the average amount of chlorine in 8 samples of Maui rain water was 11 p.p.m., while Farden (4) showed that rain water at the chemical laboratory of the Pineapple Producers' Cooperative Association in Honolulu contained 23 p.p.m. of chlorine. If these results are averaged and expressed in terms of sodium chloride, on the arbitrarily chosen basis of 60 inches of rainfall, soil in a

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* "Sorption" is replacing the older term "fixation" in referring to the process whereby soluble bases are taken up by soil and retained in a form available to plants. The term "fixation," insofar as it applies to potassium, is now usually employed with reference to a process whereby the nutrient is fixed in the soil in a form which is unavailable to plants.

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‡ The bases commonly involved in base-exchange reactions of the soil are sodium, potassium, ammonium, calcium, and magnesium. Doubtless other bases such as manganese (Mn^{++}) may take part in the process to some extent. Acid or dissociable hydrogen, although not a base, is frequently referred to as such, since in base-exchange reactions it behaves similarly. A better term for the positively charged ions which take part in base-exchange reactions is "cations."

region of this rainfall might be expected to receive 400 pounds of sodium chloride per acre per year from the atmosphere. Studies of Magistad, Horner, and Dean (9) showed that the average amount of exchangeable sodium in ten pineapple soils obtained from six islands, when expressed as sodium chloride, amounts to little more than 1,000 pounds in the surface foot of soil. If these figures approximate the true situation, then the addition of 400 pounds of sodium chloride per acre per year for untold years has not resulted in the accumulation of large quantities of the salt. It is apparent, therefore, that the soil does not always combine with this base. The following table, taken from a report on a lysimeter study by Magistad (10) indicates leaching losses from two Oahu soils which had never received fertilizer. It will be noted that losses of sodium are much greater than corresponding losses of other bases, particularly potassium. This appears to indicate also that soils receive sodium chloride from the atmosphere and do not retain it.

TABLE I

MINERALS LOST FROM UNFERTILIZED AND UNCROPPED SOILS
BY LEACHING DURING A PERIOD OF 1 YEAR

Constituent	Lysimeter No. 1 Wahiawa (Lbs. per acre)	Lysimeter No. 2 Hawaiian Pineapple Co., Field 4415 (Lbs. per acre)
Silica (SiO_2)	19.497	10.804
Alumina (Al_2O_3)	0.908	4.742
Calcium (CaO)	62.582	68.597
Soda (Na_2O)	122.619	147.372
Potash (K_2O)	15.076	28.074
Phosphoric Acid (P_2O_5)	0.459	0.401
Nitrate Nitrogen (N)	54.781	101.881
Ammonia Nitrogen (N)	1.474	0.936
Rainfall (inches)	58.450	91.630

Adapted from a report of Dr. O. C. Magistad (10).

Mechanism of Base Exchange

Many chemical reactions proceed to completion and are practically irreversible. Thus when an excess of sulfuric acid is added to a solution of barium chloride, the barium is transformed almost completely to insoluble barium sulfate and the resulting concentration of barium chloride is practically zero. This reaction is not reversible except in very slight degree.

$$BaCl_2 + H_2SO_4 \rightleftarrows BaSO_4 + 2HCl$$

Fixation of phosphates by the soil may be compared to a complete reaction of this type. Thus, Ayres (1) found that soils were able to reduce the concentration of phosphate solutions with which they were in contact from 100 p.p.m. P_2O_5 to <0.1 p.p.m. P_2O_5.

Other chemical reactions may not continue to completion but reach an equilibrium, with appreciable quantities of all of the reacting substances present. Such is

the situation when magnesium nitrate and ammonium hydroxide react to form ammonium nitrate and a precipitate of magnesium hydroxide. This reaction is readily reversible.

$$\text{Mg(NO}_3)_2 + 2\text{NH}_4\text{OH} \rightleftarrows \text{Mg(OH)}_2 + 2\text{NH}_4\text{NO}_3$$
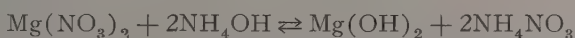
If either magnesium nitrate or ammonium hydroxide is withdrawn in part from the solution, the reaction will be readily shifted to the left and part of the precipitated magnesium hydroxide will dissolve. The addition of ammonium nitrate to the solution would similarly shift the reaction to the left and cause some of the precipitated magnesium hydroxide to reenter the solution. If, on the other hand, more magnesium nitrate were added to the original solution, still more magnesium hydroxide would be precipitated. It is to this type of reaction that the sorption of bases by soils more nearly compares.*

The materials responsible for base-exchange reactions in soils are of two totally different types. One of these consists of various clay minerals which have resulted from the weathering of lavas, or of volcanic cinders. The other is the product of the decomposition of plant materials. In either case the constituents responsible for base exchange may be regarded as extremely weak, insoluble acids or as salts of these acids. In highly leached soils from which the bases have been largely lost, the characteristic acidity of these materials appears, and the soil is consequently acid. In neutral soils these insoluble acids are present for the most part in neutralized forms, or as salts, and the bases with which they are in combination are referred to as exchangeable bases.

If the letter X is used to represent the negative radical of the exchange material of the soil, then HX will represent the acid, or hydrogen form, just as the symbol HCl represents hydrochloric acid. Correspondingly, KX, NH_4X and NaX will represent potassium, ammonium, and sodium in combination with the base-exchange material. The hydrogen, potassium, ammonium, and sodium thus indicated become the exchangeable bases, or exchangeable cations, of the soil. A chemical equation may then be written for the reaction between any soluble base and the insoluble acid or salt, as the case may be, comprising the base-exchange material of the soil. Thus the reaction between potassium chloride and a single-base soil, for example a sodium-soil, would be as follows:

$$\text{NaX} + \text{KCl} \rightleftarrows \text{KX} + \text{NaCl}$$

The corresponding reaction for a completely leached soil in which only the acid form of the exchange material is present would be:

$$\text{HX} + \text{KCl} \rightleftarrows \text{KX} + \text{HCl}$$

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* The more general treatment based upon the law of mass action is as follows: Consider the equation $a + b \rightleftarrows g + h$, in which a reacts with b to form g and h. If one mol of a and one mol of b are involved in the reaction the rate of the forward reaction is $k_1 C_a \times C_b$ and that of the reverse reaction is $k_2 C_g \times C_h$ where C represents the concentration of the reacting substance and k_1 and k_2 are specific rate constants. At equilibrium the rates of the forward and reverse reactions are the same and hence $k_1 C_a \times C_b = k_2 C_g \times C_h$ or $\dfrac{C_g \times C_h}{C_a \times C_b} = \dfrac{k_1}{k_2} = K$, where K is the equilibrium constant for the entire reaction. At equilibrium the addition of more of a or b, or the removal in part of g or h, will shift the reaction to the right. Conversely, the addition of g or h, or the removal in part of a or b, will result in forcing the reaction to the left.

Ordinarily many bases are combined with the soil exchange material. Under such circumstances the following reaction would approximate the situation qualitatively when a solution of potassium chloride is applied to the soil. In the first instance a soil containing no exchangeable potassium will be considered.

$$\left.\begin{array}{l} Ca \\ Mg \\ Na \\ H \\ NH_4 \end{array}\right\} X + KCl \rightleftarrows KX + \left\{\begin{array}{l} CaCl_2 \\ MgCl_2 \\ NaCl \\ HCl \\ NH_4Cl \end{array}\right.$$
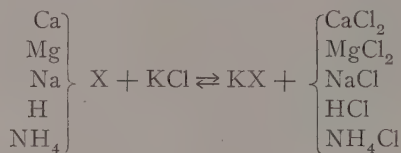
If a solution of potassium chloride is shaken with such a soil, potassium will replace some of the cations held by the exchange material and will itself be rendered insoluble thereby, or sorbed. The replaced cations, calcium, sodium, and so forth, will no longer be retained by the exchange material but will be free to move about in the solution. Some of them may again combine with the soil exchange material by displacing still other cations. Now, if the concentration of potassium chloride is increased, the reaction will be forced to the right, more potassium will be sorbed and, correspondingly, more of the other bases will be released. If, on the other hand, some of the potassium chloride could be withdrawn from the solution, the reaction would move to the left, and part of the sorbed potassium would reenter the solution, its place in the exchange material being taken by other cations. Some of the sorbed potassium could also be set free by adding to the solution one or more of the bases which had been displaced by potassium.

Suppose now, that a solution of potassium chloride is shaken with soil which already contains exchangeable potassium, e.g., a normal field soil. Whether or not potassium will enter the exchange material of the soil, to add to the supply already present, will depend upon the concentration of potassium in the solution. If the concentration of potassium in the solution is *greater* than that necessary to establish the level already present in the soil, sorption of potassium will occur. Sorption will continue until the soil and solution are at equilibrium at some new higher level of exchangeable potassium. If a potassium solution *equal* in concentration to that necessary to establish the level of potassium already present, is added to a soil, no net change will result either in exchangeable potassium or in the concentration of the solution. If, however, a solution containing a *lower* concentration of potassium than the equilibrium concentration is added to the soil, the soil will be depleted of exchangeable potassium and the solution will be correspondingly enriched. This process will continue until soil and solution are again at equilibrium with respect to potassium at a new, lower level of exchangeable potassium.*

Let us consider in terms of the mechanism of base exchange, the results which Hance and coworkers (6) obtained in their study of soils in relation to irrigation water at Hawaiian Commercial and Sugar Co., Ltd. It will be recalled that irrigation water containing 25 p.p.m. K_2O did not add to the exchangeable potassium in

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* When a solution of a potassium salt percolates through a soil, as it may following the application of a potassium fertilizer in the field, a true equilibrium is not attained so long as the movement of water continues, since the replaced bases are subject to continual removal. However, if the solution percolates slowly, a condition approaching equilibrium results, and the concentration of potassium in the solution will determine whether potassium will be sorbed or given up by the soil.

these soils, in spite of the fact that many hundreds of pounds of K_2O were applied in this manner in the course of each crop. This being the case, and since no evidence was obtained that the irrigation water had depleted the soil of potassium, it must be concluded that this concentration of potassium (25 p.p.m. K_2O) corresponds roughly to the equilibrium concentration between these soils and water of that particular composition.* Similarly, since the level of exchangeable sodium apparently was not altered by the enormous quantities of sodium chloride applied to these soils annually, it must be likewise concluded that approximate equilibrium between soil and solution obtained in the case of this base also. The failure of sodium chloride derived from the atmosphere to accumulate in Hawaiian soils is doubtless also the result of concentrations of the salt which are not above the equilibrium concentration.

Sorption of Potassium and Ammonium

Effect of Concentration and Level of Exchangeable Potassium and Ammonium in the Soil:

If the foregoing interpretation of the mechanism of base exchange is correct, it should be subject to demonstration under the conditions of control possible in the laboratory. In order to test this, substantial quantities of six soils were obtained. Large glass percolation cylinders, 3 inches in diameter, were packed with the air-dried soils to a depth of one foot. Solutions of potassium chloride were then allowed to percolate slowly through the soils. Solutions of three concentrations were employed in this work, namely, 5, 25, and 210 p.p.m. K_2O. One or more of these solutions was percolated through each soil, in increments corresponding to 5 acre-inches. Upon emergence from the soils the solutions were analyzed for potassium. The results of this experiment, together with data pertaining to the soils studied, are shown in Table II.

Referring to the table it will be seen that when potassium chloride solutions containing 210 p.p.m. K_2O, 5 acre-inches of which corresponds to an application of approximately 250 pounds of K_2O per acre were allowed to percolate through the Manoa substation and University farm soils, the resulting sorption of potassium was of a very high order. Thus the concentrations of the percolating solutions were reduced by these soils from 210 p.p.m. K_2O to around 10 to 15 and 5 p.p.m., respectively. On the basis of the earlier discussion of base exchange this concentration (210 p.p.m. K_2O) is far in excess of that necessary to cause the sorption of potassium by these two soils. In fact it is apparent from the concentrations of the leachates that potassium would be sorbed from any concentration above 13 p.p.m. by the Manoa soil and from any above 5.6 by the University soil. When a solution containing 25 p.p.m. K_2O was percolated through a Kona soil the concentration of potassium in the percolating solution was reduced to a little less than 7 p.p.m., and when percolated through the University soil it was reduced to less than 2 p.p.m. A concentration of 25 p.p.m. K_2O is likewise seen to be very much in excess of that

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* The work of Fraps and Fudge (5) and of Kelly, Brown, and Liebig, Jr. (7) suggests that the presence of considerable concentrations of sodium, calcium, and magnesium, in irrigation water, may have an appreciable repressing effect upon the sorption of fertilizer salts applied to the soil through this medium. Similarly studies of McGeorge (11) have shown that sorption of a fertilizer base by soil may be depressed by the simultaneous application of another base.

TABLE II

EFFECT OF THE AMOUNT OF EXCHANGEABLE POTASSIUM IN THE SOIL UPON THE SORPTION OF POTASSIUM FROM POTASSIUM CHLORIDE. THE EXTENT OF SORPTION IS INDICATED BY THE DIFFERENCE BETWEEN INITIAL CONCENTRATIONS OF POTASSIUM AND CONCENTRATIONS OF POTASSIUM IN THE CORRESPONDING LEACHATES

Soil	Field pH	Exchangeable potassium per 100 gms. of soil M.E.	Exchange capacity per 100 gms. of soil M.E.	Potassium saturation Per cent	Concentration of K_2O in leachate. Initial concentration 5 p.p.m.				Concentration of K_2O in leachate. Initial concentration 25 p.p.m.			Concentration of K_2O in leachate. Initial concentration 210 p.p.m.*		
					Acre-inches of leachate				Acre-inches of leachate			Acre-inches of leachate		
					1st 5 p.p.m.	2nd 5 p.p.m.	3rd 5 p.p.m.	4th 5 p.p.m.	1st 5 p.p.m.	2nd 5 p.p.m.	3rd 5 p.p.m.	1st 5 p.p.m.	2nd 5 p.p.m.	3rd 5 p.p.m.
Kona	5.7	0.40	51	0.78					6.7	6.5				
Manoa (H.S.P.A. substation)	5.0	0.48	32	1.50								10	13	—
University Farm (Manoa)	6.5	0.68	42	1.62					2.9	1.6	1.2	5.6	3.3	
Ewa	6.7	1.02	14	7.3					74	15	12			
Kailua (H.A.E.S. substation)	6.2	2.16	26	8.3	22	25	21		62	30	26	116	62	66
Aiea	5.7	1.69	15	11.3	132	60	36	43	178	45	31	182	85	

* 5 acre-inches of this solution are approximately the equivalent of 250 pounds of K_2O per acre.

1 M.E. of potassium/100 gms. of soil equals about 1,180 pounds of K_2O per acre-foot, or approximately 360 pounds of R.C.M. K_2O per acre-foot.

required to bring about sorption of potassium by these soils. Soils such as these would probably be able to obtain much potassium from irrigation waters rich in potassium.

When potassium-chloride solutions were percolated through the Aiea and Kailua soils, which are very much higher in exchangeable potassium than the three just considered, very different results were obtained. Much smaller amounts of potassium were taken up by these soils from the highest concentration (210 p.p.m. K_2O) and none whatever from the 25 p.p.m. solution.* In fact potassium was given up to the latter solution as is evidenced by the fact that the corresponding leachates contained higher concentrations of potassium than the original solutions. Here, then, the situation is one in which the solution applied to the soil is lower in concentration, although apparently only slightly so, than the equilibrium concentration, and hence leaching of potassium occurs. It is further seen that a potassium solution which leaches this nutrient from one soil, e.g. the Aiea or Kailua soil, may give up most of its potassium to another higher sorbing soil, such as the University soil. This relationship is apparent from the data in Table II. As would be anticipated from the foregoing results, the 5 p.p.m. K_2O solutions were greatly enriched with potassium as a result of passing through the Kailua and Aiea soils, the final concentrations ranging from 4 to 8 times the levels at which they entered the soils. The Ewa soil, which is intermediate in exchangeable potassium, proved to be intermediate also in its ability to sorb potassium.

These results indicate the effect which dilution may have upon the sorption of potassium dissolved in irrigation water. Suppose, for example, that 100 pounds of K_2O are applied in 5 acre-inches of mountain water. Ignoring the small amount of potassium naturally present in such water the resulting concentration will be approximately 87 p.p.m. K_2O. Suppose further that this soil is unable to reduce the concentration of the potassium in the water below 25 p.p.m. Then $25/87 \times 100$ or 29 per cent of the applied potassium will remain unsorbed by the soil. Suppose now that the same amount of potassium is applied in 10 acre-inches of water. The resulting concentration will now be approximately 44 p.p.m. K_2O. Since the final concentration will be the same in either case, i.e., 25 p.p.m. the unsorbed portion of the applied potassium fertilizer will now be $25/44$ or 58 per cent.

If reference is made to Table II it will be observed that the Kona, Manoa substation, and University soils exhibit a high order of sorption, whereas the Aiea and Kailua soils do not. The Ewa soil appears to be intermediate between the high- and low-sorbing soils. It will be seen by reference to the third column of the table that the exchangeable potassium in the high-sorbing soils is very much lower than it is in the low-sorbing soils, the Ewa soil again occupying an intermediate position. These considerations lead to the conclusion that the quantity of exchangeable potassium in the soil is the primary factor determining whether a potassium solution of a given concentration will add to or subtract from the amount of exchangeable potassium present in the soil. The correlation between sorption and exchangeable

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* In the case of the high-potassium soils, sorption from the second 5 acre-inches of solution was greater than from the first 5 acre-inches. This is probably explainable on the basis that the soils had been air-dried and hence some time was required to re-wet the surfaces of the soil particles and effect maximum sorption of potassium. Probably, also, potassium present in the soil water prior to air-drying crystallized out during the drying process and then dissolved in the first water passing through the soil.

potassium is not perfect in so far as the individual soils within a group are concerned. Thus, in the low-sorbing group, the University soil is seen to contain more potassium than either the Manoa substation or the Kona soils, yet it shows the highest order of retention. Very likely the influence of the degree of base saturation comes into play at this point, the University soil being well supplied with exchangeable bases while the other two soils are very deficient in this respect. As will be shown in a later section the ability of an acid soil to sorb potassium from a given concentration of the salt increases as the degree of base saturation is increased. Hence a soil adequately supplied with exchangeable bases may sorb potassium more efficiently than a more acid soil, even though the latter is somewhat lower in exchangeable potassium. The somewhat greater sorptive power of the Kailua soil as compared with the Aiea soil is probably explainable on the same basis. This factor in the sorption of potassium, however, appears to be of a relatively minor nature as compared with the effect of the level of exchangeable potassium in the soil.

The principles underlying the sorption of potassium by the soil should apply equally to the retention of ammonium salts. The level of ammonium in the soil should therefore be expected to exert an influence upon the sorption of this base. Due to the very small quantities of ammonium in soils, however, this factor can probably be ignored. Although ammonium is considered somewhat less sorbable than potassium, the difference in the levels of these bases in the soil may result in the greater sorption of ammonium. Earlier work of McGeorge (11) supports the view that ammonium is more highly sorbed by Island soils than is potassium.

In order to show further the effect of concentration upon the ability of the soil to take up potassium and ammonium, the following experiment was conducted.* A Hilo coast soil was deprived of its exchangeable potassium and ammonium. It was then leached with large volumes of solutions of potassium chloride and ammonium sulfate, at various concentrations, until the soil could take up no more of these nutrients. The levels of potassium and ammonium thus established in the soils were then determined. The results of this experiment appear in Table III.

Further indications are now seen of the effect of concentration upon the levels of potassium and ammonium in the soil. Thus, for example, the exchangeable potassium which was sorbed by the soil, as a result of prolonged leaching with a solution containing 4,700 p.p.m. K_2O amounted to 14,500 pounds K_2O per acre-foot of soil.† Reducing the concentration of the potassium chloride solution to one-tenth of this value, or 470 p.p.m. K_2O, resulted in the sorption of only about one third of this amount of potassium. Leaching with the lowest concentration employed in the experiment, namely 47 p.p.m. K_2O, resulted in the sorption of only about 1,300 pounds of exchangeable K_2O. Similar results were obtained with ammonium sulfate.

Effect of Degree of Base Saturation (Degree of Acidity):

Reference has been made in the foregoing discussion to the influence of the state of base saturation of soils upon the sorption of potassium. This factor in base exchange will now be considered.

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* A more detailed description of the experimental phase of this test will be found under the heading ''Degree of Base Saturation.''
† Exchangeable potassium is equal to about 3.3 times R.C.M. potassium.

TABLE III

EFFECT OF CONCENTRATION ON THE SORPTION OF POTASSIUM AND AMMONIUM BY A HILO COAST SOIL

Concentration of potassium chloride		Potassium sorbed			Concentration of ammonium sulfate		Ammonium sorbed		
Normality	p.p.m. K_2O	Lbs. K_2O per acre-inch	M.E./100 gms. soil	Pounds K_2O/acre-foot of soil	Normality	p.p.m. N	Lbs. N per acre-inch	M.E./100 gms. soil	Pounds N/acre-foot of soil
N/10	4,700	1,080	12.3	14,500	N/10	1,400	322	22.8	8,000
N/100	470	108	3.9	4,600	N/100	140	32.2	6.9	2,400
N/1000	47	10.8	1.1	1,300	N/1000	14	3.2	0.4	140

Exchangeable potassium equals about 3.3 times R.C.M. K_2O.

Soils possess definite capacities (base-exchange capacity) to hold acid hydrogen and the various bases. In the sugar cane soils of Hawaii base-exchange capacities range from about 10 to 60 milligram equivalents per 100 grams of oven-dry soil. These soils are therefore capable of holding (in the surface foot) roughly from 7,000 to 42,000 pounds of exchangeable calcium (as CaO), for example, or the chemical equivalent of potassium, magnesium, ammonium, etc. Acids from plant roots, microorganisms, and acid-forming fertilizers together with excessive amounts of water have brought about substantial replacement of exchangeable soil bases by acid hydrogen in many of the soils of the wetter districts of the Islands. In extreme cases, as will be shown in a later paper, this replacement has progressed almost to completion.

Potassium and ammonium, when applied to soils as the chlorides or sulfates, readily replace calcium, sodium, and other bases and are themselves thereby largely prevented from leaching. It has been generally held, however, that these fertilizer salts are able in only minor degree to displace the acid hydrogen of the soil, which is held more firmly than are the bases. If such is the case, then it would be logical to expect that increasing the supply of exchangeable bases in a very acid soil, and thereby decreasing by an equivalent amount the exchangeable hydrogen, as by liming, would enhance the ability of the soil to take up salts of potassium and ammonium. It was therefore decided to vary artificially the exchangeable base content of a soil representative of the more humid districts of the Islands and to measure the ensuing effects upon the ability of the soil to sorb potassium and ammonium.*

A soil from the Hilo coast district of the island of Hawaii was chosen for this study. The soil was adjusted to eight stages of calcium saturation and its ability to sorb potassium and ammonium at each of these levels was determined. The effect of exchangeable calcium upon the ability of the Hilo coast soil to sorb potassium from potassium chloride is shown in Fig. 1. Here it will be seen that, increasing the exchangeable calcium content of a completely unsaturated soil (pH 4.3) resulted in an increased uptake of potassium. The effect was slight with the lowest concentration of potassium employed but very pronounced with the highest. The concentration of this nutrient in the soil water following the application of potassium salts in the field probably varies from values which are higher than those used in this study to values which are still lower. The employment in this study of a hundredfold range in concentrations of potassium chloride should therefore indicate the general effect of increasing base saturation upon sorption of potassium under field conditions. The sorption of ammonium from ammonium sulfate was found to be equally increased by increasing the degree of base saturation of this soil.

These results indicate that both potassium and ammonium replace exchangeable calcium of the soil more readily than they replace acid hydrogen. There seems little doubt, therefore, that increasing the degree of calcium saturation in the more highly leached soils of the high rainfall districts of the Islands might well aid in bringing about increased retention of potassium and ammonium, should this be

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* A complete account of this and certain other phases of the work reported in this paper will be found in Soil Science, 51: 265–272, 1941, under the title ''Sorption of potassium and ammonium by soils as influenced by concentration and the degree of base saturation.''

considered necessary. The substitution of calcium for exchangeable soil hydrogen, however, is not the same thing as simply liming the soil. The former operation would require the most intimate contact between the particles of lime and the insoluble organic and inorganic acids comprising the soil exchange material. Under conditions of Hawaiian sugar cane agriculture, where the normal plowing interval
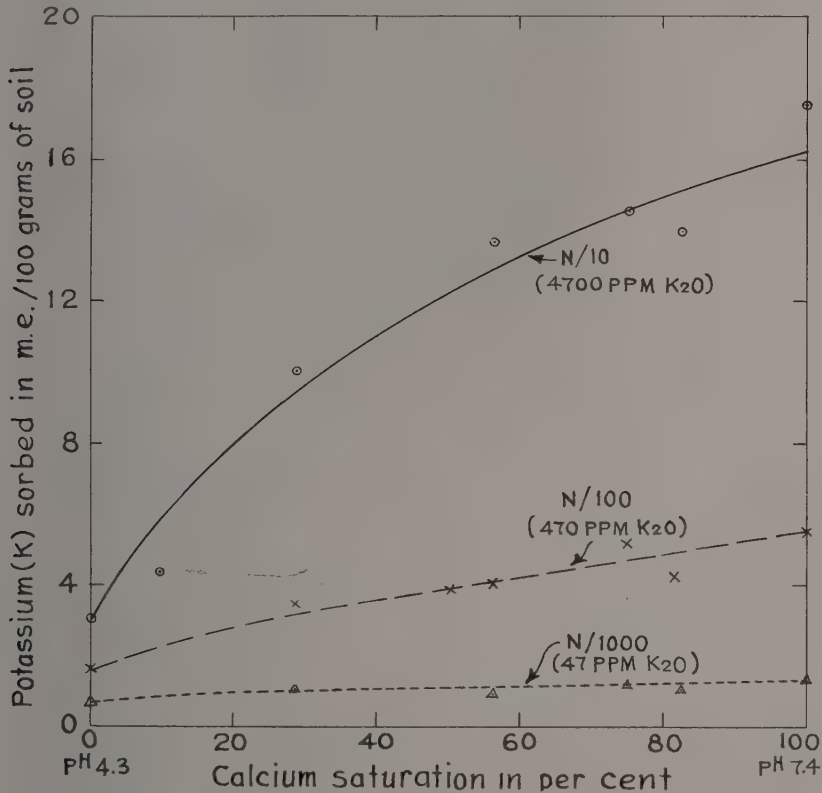
Fig. 1. This figure shows that increasing the exchangeable base content of an acid soil increases its ability to take up potassium from potassium chloride. The effect is seen to be greater the higher the concentration of potassium.

is from 10 to 15 years, such a condition would not be brought about in a reasonable period of time. Brown and Munsell (2), studying the effect of lime upon the acidity of grass land soils, found that a period of 10 years was required, following the surface application of lime to the soil, before a uniform pH was attained in the top 6 inches of soil. The unaided diffusion of calcium through the soil is thus seen to be an extremely slow process.

Effect of the Form of the Fertilizer Salt:

In order to determine the effect of sulfate and chloride ions upon the sorption of potassium and ammonium by very acid soils, portions of the Hilo coast soil

from which all bases had been removed by electrodialysis (pH 4.3) were leached with solutions of potassium and ammonium in both the chloride and sulfate forms. The extent of the resulting sorption of the nutrient bases is indicated in Table IV.

TABLE IV

INFLUENCE OF THE ANION (CHLORIDE AND SULFATE) ON THE SORPTION OF AMMONIUM AND POTASSIUM BY A HYDROGEN-SATURATED HILO COAST SOIL (pH 4.3)

(Results expressed in M.E./100* gms. of soil)

Concentration of salt	Potassium sorbed from		Ammonium sorbed from	
	Potassium chloride	Potassium sulfate	Ammonium chloride	Ammonium sulfate
N/1000	0.7	1.2	0.0	0.2
N/100	1.6	3.4	0.8	3.1
N/10	3.0	10.6	3.3	10.4

* 1 M.E./100 gms. soil equals 1,180 pounds of K_2O per acre-foot of soil *or* 350 pounds of N per acre-foot of soil.

It will be seen that at all concentrations employed, but particularly at the two higher ones, sorption of potassium and ammonium was greater from the sulfate than from the chloride forms of the salts. Such results in the case of acid soils might be anticipated, since sulfates have a slight tendency to render acid hydrogen inactive and thus aid in the sorption of the associated base, whereas chlorides do not possess this property. Recent studies of Koch (8) with Ceylon paddy soils have also shown that ammonium is somewhat more highly retained by soils when applied as the sulfate than as the chloride.

In the above test with the Hilo coast soil, the soil was thoroughly leached with solutions containing relatively large amounts of potassium and ammonium. Subsequent to this experiment, attempts were made to demonstrate differential effects of chlorides and sulfates upon the sorption of the associated bases under conditions corresponding more approximately to normal field practice, with very much larger quantities of soil and relatively smaller amounts of fertilizer salts. Two untreated acid soils were used for these tests, an Aiea soil of pH 5.7 and a Manoa soil of pH 5.0. Under these conditions both the sulfate and the chloride forms of ammonium were sorbed so highly (above 95 per cent) that the anticipated differences were not observed. In corresponding tests with potassium, while there were indications of greater retention of the nutrient from the sulfate than from the chloride form, the differences were not considered great enough for significance. Seemingly then, the effect of the non-basic constituent of the fertilizer salt cannot be expected to be very pronounced on Hawaiian soils where the amount of the salt used is as small, relative to the quantity of soil, as it is in ordinary field practice.

Effect of the Permeability of the Soil:

Hawaiian soils differ greatly in their resistance to the downward passage of water. Irrigation water may remain on the surface of some soils for hours, or even overnight. On other soils it may disappear in a matter of minutes. Soils of

unirrigated plantations likewise exhibit varied resistance to the movement of rain water. The degree to which soils are able to remove fertilizer salts from solutions of these materials percolating through them is dependent in considerable measure upon the length of time the salts and the soil are in contact. If water containing potassium or ammonium passes rapidly through the soil there will be less opportunity for reaction between the salts and the base-exchange material of the soil than would be the case if the downward movement were slow. The results of two tests showing this influence will be found in Table V.

<div align="center">TABLE V</div>

<div align="center">INFLUENCE OF RATE OF PERCOLATION ON SORPTION OF AMMONIUM</div>
<div align="center">(Treatment 250 pounds N from ammonium sulfate in 5 acre-inches of water)</div>

<div align="center">Manoa Soil   Aiea Soil</div>

Time of percolation (Min.)	Loss of Nitrogen (N)		Time of percolation (Min.)	Loss of Nitrogen (N)	
	Pounds	Per cent		Pounds	Per cent
31	10.5	4.2	16	27.4	11.0
68	4.0	1.6	24	27.4	11.0
150	0.35	0.14	75	12.5	5.0
. . .	. . . .	. . . .	225	9.5	3.8

The quantities of ammonium "lost" in the present experiment perhaps bear little relation to possible corresponding losses under field conditions, yet they illustrate the effect which the rate of water movement has upon the retentive ability of the soil for this nutrient. Increasing the time of percolation of 5 acre-inches of solution through the Aiea soil from 16 to 225 minutes reduced the ammonium losses from 11 to less than 4 per cent. Retarding the rate of percolation through the Manoa soil made possible all but complete sorption (99.9 per cent) of the added ammonium sulfate.

<div align="center">SUMMARY</div>

A study was made of the influence of the levels of exchangeable potassium and ammonium, concentration, degree of base saturation, form of fertilizer salt, and rate of penetration upon the sorption of these bases by Hawaiian soils. The results may be summarized as follows:

1. Evidence was obtained which indicates that sorption of potassium is primarily dependent upon the level of exchangeable potassium in the soil. Sorption was of a lower order the greater the amount of exchangeable potassium present. This factor can be ignored in the case of ammonium due to the low levels of ammonium in soils.

2. It was found that there is a concentration of potassium for any particular soil above which sorption will occur and below which sorption will not occur. In the case of the soils studied, these concentrations were from 2 to about 30 p.p.m. K_2O.

3. The amounts of potassium and ammonium which soils can sorb from solutions percolating through them were found to increase with increasing concentrations of these bases.

4. Reducing soil acidity by increasing the degree of calcium saturation increased the sorption of potassium and ammonium salts.

5. More potassium and ammonium were sorbed by hydrogen-saturated soil (pH 4.3) when leached with large volumes of the sulfates of these bases than when similarly treated with the chlorides. When unaltered soils containing some bases were treated with amounts of these salts approximating field practice, no differences were observed.

6. Retention of ammonium was found to be higher the slower the rate at which solutions containing this nutrient percolated through the soil.

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Contributions of the Entomologists to Hawaii's Welfare*

By C. E. Pemberton

It is quite probable that the original Hawaiians had little or no need for the services of a trained entomologist and, in fact, got along very well without him. Even if we could by some means go back to their days, sensitive and critical as we are, we would hardly find a single insect species sufficiently prominent, annoying or destructive to warrant our wordy abuse. This would not be owing to an absence of insects. Actually there were at least three thousand species, but they were native in a very strict sense of the word. They had been here for untold hundreds and thousands of years. They were settled, balanced, controlled and adjusted to nature's scheme of things in Hawaii to a point where each had its place under the sun and no more, thus constituting what we aptly term "the balance of nature." We know that such a Utopian state actually was maintained amongst the Hawaiian insects at that time. If we go into the undisturbed forests today, these native insects can still be found living in much the same relation to each other and to their hosts as they did long ago. We will find none that can be classed as actual pests. Perhaps the coconut leafroller and the sugar cane leafroller may be listed as pests, but there is some evidence to support the belief that at least the former, which is the worse of the two, is a recent introduction though neither are known elsewhere. (O. H. Swezey recently pointed out to me a statement appearing in Hillebrands' *Flora of the Hawaiian Islands* in which the author remarked that "For a number of years, however, its leaves have been subject to the attacks of a moth which deposits its eggs in the folds of the leaf-segments. Before the caterpillars have entered the pupa stage the young leaves are literally reduced to shreds, which gives to the trees a sad appearance and creates in the occasional visitor the impression that they live under unsuitable climatic conditions." This observation was made prior to 1871 when Hillebrand was last in Hawaii.) There is the strong suggestion here that this leafroller may have reached Hawaii sometime within the past century and is not native.

It might thus be stated as an entomological maxim that those regions, which have had the least change in the species and ecology of their fauna and flora and have been least altered by man over a long period of time, will have the fewest devastating epidemics of insect pests (if any) and the fewest breaks or large shifts in the so-called "balance of nature." However, where these changes have been large and frequent, owing almost solely to the operations of man, insect troubles amongst others become manifold.

Hawaii is one of these places. Here the changes in our flora and insect fauna have been very great within the short period of about 100 years. Almost every

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vestige of the original lowland flora in many places has been swept away and re-placed with imported vegetation comprising a long list of plants both desirable and undesirable and with them have come hundreds of insects entirely new to the Terri-tory. Also buildings and streets now cover thousands of acres of land once clothed in native vegetation (such as it was) and even our mountain forest reserves contain an ever increasing variety of introduced plants, some being unwelcome intruders. Changes have thus been profound, and continue; much of the natural equilibrium maintained amongst our plants and animals through centuries of association has been upset. In fact almost everything but the geology of terrestrial Hawaii has changed tremendously since the coming of Captain Cook, and perhaps the geologist will contest even this statement.

From the entomological viewpoint these changes would not have seriously inter-fered with the affairs of man in the Islands had he not brought with him, un-avoidably and unintentionally, a large number of insects new to Hawaii. Many were on or in the plants he brought, while some were in the soil that came with some of the plants. His cows, horses, dogs, cats, poultry and even rats also housed differ-ent insects, which enroute from distant lands came ashore with their respective carriers shortly after the early sailing vessels dropped anchor in this Paradise. In the ship's water tanks were mosquito larvae, in other parts were roaches of several species together with bedbugs and other bugs, while in precious seeds and other foodstuffs were weevils and moth larvae and in some of the wood (of course) a termite or two. Some of these insects undoubtedly failed of establishment, but a large number found conditions highly suitable and soon became conspicuous on the landscape. And so today almost every insect one sees about Honolulu, or any-where outside the native forest areas, is foreign to the Islands and came in as an intruder or was purposely brought in during modern times for beneficial purposes. There are of course a few exceptions.

It is a curious but well-established fact that many plants and animals, when moved away from their own original geographical barriers and placed in a region ecologically suitable, thrive and multiply much better than in their home countries. The prickly pear from America offers a striking case in Australia, where it over-ran millions of acres before it was stopped with an insect specifically attached to it in America and which controls it there. Fiji has had a similar experience with a so-called weed, *Clidemia hirta,* imported with coffee from Brazil some 50 years ago. It completely swamped valuable lowland pastures and when seen by the speaker in 1920 formed large impenetrable thickets. A South American insect, occurring in Trinidad and living naturally on this weed, was finally introduced into Fiji in 1930 and so completely controlled the plant that when examined again in 1938, original jungles of this pest 6 feet high had disappeared and the land was changed to clear grassy pastures. The insect damage to *Clidemia* had been sufficient to permit other competing vegetation to smother out the hardy immigrant. Lantana is another American plant that thrives and spreads with exceptional rapidity when taken far from home and planted in tropical lands in the absence of its natural insect foes. These cases have many counterparts amongst the insects.

In spite of the fact that Hawaii has some three thousand native species of in-sects, hardly any are conspicuous or troublesome, whereas all of the real pests are trespassers from other countries and came to us in rather modern times. Why

should the immigrants be pests and the indigenous forms remain innocuous? The partial answer has been expounded so often that it hardly needs repetition. The native species have their own peculiar natural enemies together with other control factors of which we know very little, whereas most of the immigrant pests came without the natural enemies, diseases, etc., which kept them in check in their home lands, and the very limited and specialized Hawaiian fauna offered little or nothing in opposition to them in the form of effective parasites, predators, diseases, etc. This explanation sounds almost too simple to be accepted as fact. Repeated experience has proved the reasoning to be basically sound. With suitable plant hosts present many introduced insects can be expected to multiply prodigiously. Even if their natural insect enemies came with them, such parasites would have great difficulty surviving because of the scarcity of the pest during the first generation. Foreign pests have actually run rampant in Hawaii in a number of cases and in some the very existence of at least one major industry has been seriously threatened. These problems have been solved one by one through recognizing and acting upon the biological facts of natural control just indicated. The results were so gratifying from the very beginning that this method of control has long been standard practice in Hawaii and has attracted world-wide attention. In fact nowhere has the method been so persistently applied with more economically profitable returns.

These highly successful results in the control of insect pests in Hawaii by biological ways were accomplished only because the stage was perfectly set for the application of such a method long before man discovered these Islands, and the stage is still set for further returns, to our benefit, if we continue to apply this system of insect warfare against pests yet out of control. By a set stage we refer to the ease with which many insects can multiply when brought into Hawaii from other parts of the world, and fortunately this applies not only to harmful insects but to beneficial ones also. This makes it possible for the entomologist to accomplish amazing results sometimes.

Insect parasites and predators can usually be expected to work much more efficiently here than in continental areas, providing their hosts are present. There are several reasons for this and they will be different for different insects. For instance the Philippine parasite which we used to call *Scolia manilae* has accomplished a very thorough control of the oriental Anomala beetle on certain Oahu sugar plantations where it became established many years ago, but this same parasite has been repeatedly introduced into New Jersey for control of the same insect—entirely without success. After liberation it disappears and is never seen again. As another instance we mention the avocado mealybug *Pseudococcus nipae*. There was a time when it was a positive nuisance in Hawaii—many trees and shrubs were simply plastered with this mealybug. The speaker has seen avocado trees, guava shrubs and banyan trees about Honolulu positively dripping with honeydew secreted by the myriads of mealybugs on these plants. Park benches in Honolulu where banyans furnished welcome shade during hot days were dirty and sticky from this honeydew. In Mexico where this mealybug is native, it can be found without difficulty, but there it is checked by the minute encyrtid wasp *Pseudaphycus utilis*. When this wasp was introduced into Hawaii it not only checked the mealybug, as it does in Mexico, but went much further. In the opinion of many entomologists in Hawaii today, it succeeded in eradicating the mealybug and in so doing eradicated

itself, since it completely destroyed its own food. It has now been many years since any entomologist has been able to bring to light either the mealybug or the parasite. If this is not control in the fullest use of the word, then what is control? There are many other cases of a similar nature though not so absolute.

So, given the ability to find and introduce the best possible natural enemies of any particular immigrant insect pest, the entomologist of Hawaii will usually succeed famously. We are not making the most of the opportunities this set stage offers us—there is still a great deal to do. Lest we lose faith in the virtues of this biological method, we need to be frequently reminded of some of the triumphs achieved in the past.

Had it not been for the service rendered to Hawaii's sugar industry by entomologists, this large and important business would long since have ceased to exist. This is no idle statement unsubstantiated by facts. The sugar cane leafhopper would alone have eliminated sugar cane as a profitable crop here 35 years ago had it not been brought under control by natural enemies. During 1904–05 and 1906 when it swarmed over the cane fields and not only threatened but brought complete ruin, the combined efforts of managers, chemists and practical field men were absolutely futile in coping with this problem. Insecticidal and other artificial treatment was out of the question because of the expense and insurmountable difficulties of application to thousands of acres of cane jungle. However, a seemingly hopeless situation was in a few years almost completely alleviated following the planters' appeal to two entomologists who were in Hawaii at the time. The planters no doubt felt that they were grasping at a last and doubtful straw. Probably all of you know the history of this case. It demonstrated most clearly that experienced and successful farmers, broadly educated and versed perhaps in many sciences, were in this case absolutely helpless without an intimate understanding and training in the science of entomology. Dr. R. C. L. Perkins and Albert Koebele, to whom the planters appealed for help, were experienced and thoroughly schooled entomologists. They fully understood the facts of biological control amongst the insects, as judged from their own wide experience in the field. Their solution of the problem was clearcut, comparatively simple and accomplished in a reasonably short time at less cost than that of a tourist taking a jaunt across the Pacific to see the wonders of the other side. Perkins and Koebele knew little of insecticides and probably cared less. Their solution of the difficulty was accomplished entirely through natural or biological channels, thus saving a huge industry which otherwise would undoubtedly have fallen into the discard.

This work attracted wide attention. The results were so striking that faith in the ability of the entomologist to work miracles in Hawaii, at little expense, grew rapidly among the men who controlled and developed the major industries of the Islands. Through their support, entomological staffs grew, more miracles were worked from time to time and even today the general feeling prevails that the entomologist can prevent or quickly abate devastating insect epidemics of the future. Generally speaking he probably can. We have the recent case of the taro leafhopper which was well on its way by 1937 toward the complete ruination of taro on Oahu. Costly methods of control or eradication by artificial means were tried and failed most dismally. Realizing the futility of artificial measures, D. T. Fullaway went to the Philippines and in a very short time successfully collected and shipped

to Honolulu the natural enemies which control the hopper in the Philippines. This work effected a complete and permanent control here and the suffering taro plants have returned to their normal and healthful status. One need only talk with the taro planters to be fully convinced that biological methods of insect control can be and are tremendously effective. It is a most remarkable vindication of the parasitic or natural method of checking insect pests in Hawaii. Who but a thoroughly trained entomologist, experienced in the lore of identifying and tracing the origin of insect species, could have accomplished this so quickly—or at all.

Conspicuous among other insect pests of foreign origin, which have been success-fully checked by biological methods in Hawaii, may be mentioned the sugar cane beetle borer, the pink and the grey sugar cane mealybugs, the filamentous mealybug (*Pseudococcus filamentosus*), the cottony cushion scale, the sugar cane aphis, the coconut scale (*Pinnaspis buxi*), the fern weevil (*Syagrius fulvitarsis*), the Chinese grasshopper, the mole cricket, and the torpedo bug (*Siphanta acuta*). To a lesser extent many other insects have been considerably checked by imported parasites and predators and the benefits derived have greatly justified the small expenditures of time and money involved. Conspicuous among these are the Mediterranean fruit fly, the status of which has been materially altered since the establishment of several parasites; our two grass armyworms (*Laphygma exempta* and *Cirphis unipuncta*) and several cutworms; the rice stem borer (*Chilo simplex*); the coconut and sugar cane leafrollers; several seed weevils or Bruchidae; and the garden looper (*Plusia chalcites*). These insects do cause annoyance at times and by some residents would be considered still out of control, but the change since their various parasites have been introduced has been very much for the better. In the case of the coconut leaf-roller, most residents who have been in Hawaii over 25 years will recall the ragged and unsightly appearance of the coconut leaf fronds all about Honolulu which was caused by mass feeding of the caterpillars of this moth. We see very little of this today on the leeward side of Oahu and when it does appear, the oriental parasite *Cremastus flavo-orbitalis* parasitizes a high percentage of the caterpillars. This parasite was unknown in Hawaii prior to 1910. Even the so-called Japanese beetle is now often extensively parasitized by one of the Anomala parasites brought in from the Philippines in 1917. There are also a good many other foreign pests here that have undergone considerable subsidence since parasites have been introduced. Among these are a number of scale insects which are preyed upon by quite a list of parasites of foreign origin.

Very few present-day residents in Hawaii can fully realize or appreciate the extent to which many of our imported pests are actually under control by intro-duced enemies. This is especially true of those insects which were brought under control a decade or more ago. It is easy to forget the serious damage caused by a pest 20 years ago and fall into the habit of bitterly complaining over some infesta-tion that is actually mild compared with the early difficulties encountered before parasites were introduced.

Control can be economically successful without an approach to eradication. Many of our insect pests are actually under good biological control though they can be found almost any time. The layman is inclined to condemn any so-called control unless it is absolute, whereas he little realizes, without actual experience, the differ-ence between partial control and no control. The grass armyworm *Laphygma ex-*

empta is a good example of this. Periodically, and almost annually, this moth becomes numerous in certain grasslands and on many of the sugar cane plantations. Its caterpillars destroy a large amount of leaf material over a period of several weeks and sometimes several months at a time. But a complex of parasites and diseases ultimately come to the rescue and the trouble rather suddenly stops, the complaints cease, and finally a normal crop of cane is harvested or the affected pasture lands break out in new lush grass. There is of course some loss, but we hesitate to predict what the situation would be if none of these parasites or diseases moved in to stem the tide as the geometrical increase of the armyworm progressed into the fourth or fifth generation.

The sum total of benefit derived continuously from the various useful insects intentionally imported into Hawaii unfortunately cannot be measured in tons of food, in dollars, comfort or pleasure; but it is so large that the cost of maintaining the few entomologists required to build this condition is infinitely small. Once a beneficial insect is established, the gain thereafter is continuous and permanent and the insect requires no further attention on our part.

Biological control programs are by no means always successful. We have had many failures. Sometimes the best efforts of fully qualified men are not crowned with success and there is a long list of beneficial insects introduced into Hawaii which failed of establishment. Of these failures and the work involved, the average resident hears little. Sometimes the insect which failed of establishment was obtained with greater effort and expense than some of the highly successful introductions. Few realize the sacrifices and disappointments which are sometimes the lot of the entomologist engaged in foreign exploration for beneficial insects. However, the fascination of pursuing the unknown is usually ample compensation for most of the failures and there are nearly always a few victories that fully atone for the defeats.

It is not only the men who have actually discovered and introduced these useful insects into Hawaii who have contributed permanently to our welfare. Those on the receiving end have had the extremely important duty of rearing the parasites and excluding the elusive and dangerous secondaries (parasites on parasites), which unavoidably accompany many shipments and which can undo all the potential value of the primary parasites.

There are other important contributors who have participated in this biological control work, who are usually unsung and unrecognized by almost everyone but the men actually engaged in the field work. These are the entomologists composing the comparatively obscure group whose work is purely taxonomic. In the last analysis the parasite hunter is almost helpless until he learns the identity of the insect for which natural enemies are sought. This enables him to immediately consult the world literature and discover what is already known of the insect if it is not a species new to science. But even if it is a new species, the taxonomist will usually be able to throw much light on the world distribution of closely related forms and rather accurately indicate the region where it is probably indigenous. Without the aid of the taxonomist, or access to his published work or well-ordered collections, the parasite hunter must grope blindly like an untrained prospector for oil who has no advance knowledge of petroleum geology to guide him into favorable localities. The museum is the taxonomists' workshop. To the casual visitor it deals with

things dead and of the past, but to our parasite hunter setting out on his trail, it throbs with material of immediate and practical value.

The building up of museum collections of insects, involving the identification, ordering and maintenance of thousands of specimens, is a slow and exceedingly laborious process. The insects are not simply specimens on pins put away in boxes to idly amuse visitors by their curious shapes and beautiful colors. The minutely and carefully lettered labels attached to every pin are as valuable to the collection as a track to a railroad train crossing a continent. As every entomologist knows, a pinned insect without a label, telling at least when and where it was collected, is comparatively worthless. Someone has said "A pinned insect without a label is of less value than the label without the insect."

The unending and tedious work of pinning, labeling and identifying the thousands of insects housed, let us say at the Bishop Museum, is a contribution to Hawaii's welfare of large proportion. It embraces the work of not only the Museum entomologists but also of specialists all over the world. The collection tells us almost at a glance a great deal about the species of insects scattered over the Pacific Ocean and particularly Polynesia.

Twenty years ago the speaker had occasion to utilize in a very striking way and with economic benefit to us in Hawaii, the meagre data included on an insect label in an obscure collection of insects in Australia. A fern weevil, *Syagrius fulvitarsis,* definitely foreign to Hawaii was devastating the beautiful Sadleria ferns of the Kilauea forest reserve on the island of Hawaii. It had been in the Islands a good many years. Entomological literature, museum collections and weevil specialists were consulted to determine, if possible, the source of this pest—but without avail. There were no apparent records of its occurrence anywhere outside Hawaii excepting under artificial conditions in greenhouses in Sydney, Australia, and Dublin, Ireland. Nor were any related species known anywhere. Without a clue to its origin there was little hope of finding efficient or specific natural enemies for it. Local parasites in Hawaii took no interest in it and there was justifiable fear that the weevil would ultimately eradicate large areas of fern cover in our important forest reserves to the great detriment of many of the native forest trees, highly sensitive to such an ecological change.

Purely by chance a single specimen of this weevil was found in an old and private collection of insects in Sydney while the speaker was in Australia engaged in another pursuit. The old and faded labels on the pin, which held the beetle, released the secret for which entomologists had been searching for many years. The specimen had been collected in a forest area in New South Wales in 1857 by an entomologist named French. The labels read "Wien Wien, Richmond River, New South Wales, 1857, French." The few moments French gave to pinning this beetle, attaching the labels and storing it in a box to be placed in a small museum, was a contribution of great value of which he little dreamed. Sixty-five years later the specimen gave us the necessary clue to the original habitat of the species—the rest was simple. Some of the forest region indicated on the label was found to be still in its original, pristine condition, though circumscribed by farms. The weevil, though very scarce, was soon found amongst some of the ferns and its larvae were well parasitized. Within a few weeks the parasite had been shipped to Kilauea and established. Satisfactory and permanent control of the pest followed.

This exemplifies in rather spectacular fashion how museum collections of insects can be of permanent economic importance and may serve usefully at unexpected times. During the past thirty years extensive collections within the Pacific have been made by entomologists financed with Hawaiian capital. These are contributions of great value to the future. Much of the material is deposited in the Bishop Museum. Other large collections, which are invaluable for immediate reference when needed, can be found at the Board of Agriculture and Forestry and the Experiment Station, H.S.P.A. These are being frequently added to. Recently extensive additions have been made through foreign exploration and collection within the Pacific by Messrs. Swezey, Zimmerman and Williams. With the great increase in travel over the Pacific by commercial and naval steamers and airplanes, danger of new pests reaching our shores in spite of quarantine restrictions is rapidly growing. These collections are thus becoming contributions of greater and greater utility for reference purposes. They constitute vital aid to the solution of future problems in the biological control of new pests which we cannot anticipate at present. Such collections have many other uses which we will not discuss here.

There are other fields of endeavor in which entomologists of Hawaii have served the Territory with great credit to themselves and the profession. For many years the pineapple industry suffered great losses from a malady to the plants now designated as "mealybug wilt." The establishment of proof that the mealybug *Pseudococcus brevipes* was responsible for this particular kind of wilt, and the development of highly effective artificial measures for control of this insect have been contributions of huge monetary value to the industry and the Territory.

Thirty years ago mainland markets were closed to most Hawaiian fruits and vegetables because of Federal and State quarantines erected against this Territory to prevent the Mediterranean fruit fly and melon fly from spreading to the California coast and beyond. This has had a considerable effect in discouraging diversified agriculture here. Recently entomologists of the Fruit Fly Laboratory of the U. S. Bureau of Entomology and Plant Quarantine in Honolulu have perfected processing methods which render Hawaiian fruits and vegetables safe for shipment to the mainland. As a result the quarantines have been modified and new markets have been opened for products which have long suffered the heavy handicap of a quarantine barrier. It is possible that this may ultimately lead to prosperity for many of Hawaii's small farmers.

Little has been accomplished in the past to perfect insecticidal control of many insects which attack and often ruin some of our food crops and ornamental plants. Small gardeners have struggled against great difficulties and have had little constructive help or advice in problems that are strictly within the field of entomology. In recent years this situation has been improved with the reorganization of the department of entomology at the University of Hawaii and with the appointment of an entomologist and horticulturist at the Hawaii Agricultural Experiment Station.

A valuable service contributed by entomologists of the Territorial Board of Commissioners of Agriculture and Forestry, which is apart from insect control, has been the development of a completely satisfactory and practical method of chemically protecting wet-land taro of Oahu against an imported crayfish, which only a year or so ago marched through much of our taro lands with disastrous effects.

Another branch of the Board, the Division of Plant Quarantine, is primarily a service staffed by entomologists, and it has long been absolutely essential to Hawaii's welfare. As proof of the effectiveness and value of this service to the Territory, it is only necessary to state that the great majority of our most pestiferous insects gained entrance to these Islands before the Division of Plant Inspection was thoroughly organized.

In many ways entomologists have thus found useful work to do in Hawaii. They should be as much in demand in the future as in the past. The community will expect and probably receive entomological aid over a still wider field than at present. Staffs should be increased wherever possible, since it is not likely that the calls for assistance will decrease.

But in any plans for the future the greatest and most permanent good, for the largest number of people at the least expense, will almost certainly come from continued exploration and research in biological control. Without question most money already spent in this branch of entomology has paid handsome dividends and continues to do so. We should not be content to rest on our laurels and assume that the best to be had of beneficial forms are already here. There are still large and promising fields in the realm of beneficial insects open and waiting for our investigation. If we are to make the most of the opportunities so offered, one or more field laboratories in specially selected foreign regions, continuously operated by rotating entomologists from Hawaii and financed by local institutions, public and private, should be maintained. The cost of keeping entomologists in the field is hardly greater than if they are kept at home, excepting where all living expenses are paid by the employer.

Some years ago a prominent and successful Honolulu business man, having full knowledge of the part biological methods played in the control of some of our worst pests, suggested in conversation with the speaker, that Hawaii would be better off if most of the well-trained entomologists who live in Honolulu were to reside and draw their salaries in some foreign country instead of here at home. It was his opinion, strongly put, that no entomologist could find or conjure a new and useful insect in Hawaii unless it were already here and that at least he ought to spend some of his time in foreign tropical regions where even chance alone might bring to his attention insects potentially useful for these Islands. His reasoning was perfectly sound. It has been the common experience of entomologists engaged in biological control investigations in foreign countries to find many useful parasites and predators of which they had no prior knowledge. We could even name a good many beneficial insects already recorded in foreign countries which would be very well worth trying here.

The work of Albert Koebele furnishes a beautiful example of what we can expect from capable entomologists placed in rich entomological fields, free to roam and investigate at will, with no special and hampering obligations other than the broad problems assigned them. Koebele had special assignments, but he seemed to carry all of Hawaii's insect troubles in his mind as he wandered in foreign countries. Many of the beneficial insects in Hawaii today were observed and introduced by him during many years of travel in China, Japan, Ceylon, Australia and Mexico. He was sufficiently familiar with our insect problems to know when he came across an insect that might be useful here. The sum total of his miscellaneous introduc-

tions is of very great value to this Territory. Much that he found was undoubtedly new to him, since literature in those days could have only served as a poor guide to what he might expect. He found these useful insects only because he was in the right field and was qualified and enthusiastic for work he must have known would pay. There are a good many entomologists in Hawaii now who have done the same sort of work and are fully capable of doing more of it. If staffs are maintained as they are today, there will always be a sufficient number of men to handle both the home and foreign work. There are no special or serious problems at present, but we should not wait for some serious emergency to stimulate us to further importations of beneficial insects.

Returning again to our business man who would like to see more of Hawaii's entomologists living far away but still on our payrolls, the question was asked, "Where can we expect to find the greatest assembly of beneficial insects adaptable for use in Hawaii?" Without question the natural zoogeographical region classed as "Oriental" would best suit us. This region embraces India south of the Himalayas, Southern China, Malay Peninsula, Sumatra, Java, Bali, Borneo and the Philippines. To this must be added much of the Australian region also, which includes Australia and the rest of the Malayan Archipelago not already mentioned. In the Australian region we will find New Guinea and some islands to the west particularly fruitful. It is this part of the world, south and west of us, that gave origin to a great deal of Hawaii's native insect fauna and, curiously enough, much of our man-imported pest fauna came from there also. As already indicated several times, it is in these places of origin that the greatest number of natural control factors will be found. The maintenance of a so-called parasite laboratory in Ceylon, the Federated Malay States or the Philippine Islands for several years would unquestionably pay for itself many times over, if continuously staffed with a few of our qualified men. An entomologist's laboratory to serve the particular purposes required in the present suggestion need consist of hardly more than a few microscopes, a proper assortment of glassware and a few other simple tools of the profession, all housed in a room or two. It is not the laboratory that is essential. Entomologists today can usually conduct such work near centers of civilization where museums, libraries and contemporary scientific workers can be found. We suggest Kuala Lumpur, Federated Malay States, as approaching the nearest to an ideal locality for our foreign parasite laboratory. It is not only here that entomologists have lived and worked for many years and built up a splendid and well-ordered entomological collection, but the country is one of the richest in the world with respect to fauna and flora, and now lies in point of time by air mail, fairly close to Hawaii.

To mention a few of Hawaii's insect pests which occur naturally in Malaya, or have their close counterparts and which most probably have parasites or predators there of importance which we need in Hawaii, the following are listed:

The sweet potato stem borer (*Omphisa anastomosalis*). The larvae of this moth seriously damage the stems of sweet potatoes and may even bore down into the tubers. Parasites are badly needed and probably could be found in the Indo-Malayan region where this insect is known and is almost certainly native. The rice borer *Chilo simplex,* belonging to the same family of moths and of Oriental origin, has been investigated by Hawaiian entomologists in the Orient. Parasites were

found and introduced into Hawaii. One of them which became established has also taken to this sweet potato stem borer and is doing some good on Oahu. This serves to show that other and probably more specific parasites of the stem borer could be found if search were made for them. We hear a great deal these days about the utility of the sweet potato as a source of food in Hawaii in case of an emergency. In the event of large plantings, maintained over a considerable period of time, we can expect this borer, as well as some other of the sweet potato insects, to become very important pests of this crop and production may be seriously curtailed.

Our cone-headed, pink-winged grasshopper *Atractomorpha ambigua* is of Oriental origin. Species of the same genus occur in Malaya. Though parasites and other natural enemies are unknown, careful exploration has not been made in this field and the chances are good that such could be found. Our green grasshopper, which we call the Chinese grasshopper *Oxya chinensis,* was not known to have parasites in Malaya until we investigated it during 1930 and found parasites which now satisfactorily check it in Hawaii. This suggests that parasites could probably also be found for *Atractomorpha.*

Both the coconut leafroller *Omiodes blackburni* and sugar cane leafroller *Omiodes accepta* are unknown elsewhere, but there is every indication that they, or rather their ancestors, are of Indo-Malayan origin. Parasites of related forms in Malaya or India should be introduced into Hawaii and tried. The best we yet have for these moths is the Oriental wasp *Cremastus flavo-orbitalis.*

The hibiscus white fly *Aleurodes hibisci* has long been considered a native of Hawaii. It is often so abundant on certain varieties of hibiscus as to suggest that it is of foreign origin. A few years ago we learned that it occurs in Formosa, where it is said to be rather uncommon. This strongly suggests an Oriental origin and offers another nice opportunity for the traveling entomologist to accomplish a useful work in biological control.

The rose beetle or Chinese beetle *Adoretus sinicus,* commonly known here as the Japanese beetle, is definitely from the Oriental region. It is known in southeast Asia, Java, Timor and Formosa. This and related species can be readily found in this general region and are known to have a number of natural enemies, some of which have already been tried on Oahu without success. It does not appear that parasites of importance will be found until investigators have opportunity to live in the natural field of activity of this pest and its closely related cousins for a considerable length of time and have a free hand to thoroughly study and determine its natural enemies.

The mango weevil *Cryptorhynchus mangiferae* is known to occur all the way from Africa, through Indo-Malaya into the Philippine Islands. It is perhaps native in the Oriental region and should have some natural enemies, though none are recorded. It does not seem to be nearly as important there as in Hawaii. We suspect the reason no parasites are recorded is because little attention has been given to the subject outside of Hawaii, since it is unimportant elsewhere as a mango pest. Certainly the beautiful mangoes of the Philippines are much less affected by this weevil than are the mangoes of Hawaii. We should try and determine the reason.

There is a pretty little bluish-purple butterfly *Cosmolyce boetica,* with a wing-spread of about an inch or more, whose larvae feed in the pods, seeds and flowers

of a large number of our leguminous plants. It is a pest of importance in these Islands and has been known here for at least 60 years. It is believed to have come originally from some part of that portion of the world lying between Africa and Japan and is known all the way between. Natural enemies of importance probably occur within the Indo-Malayan region and should be easy to obtain by any capable investigator. Dr. Williams has recorded one parasite which occurs in the Philippines.

The cabbage webworm *Hellula undalis* has been in these Islands at least since 1892. It is known in Indo-Malaya but is considered of minor importance there. The reason for this comparative scarcity should be determined and can only be accomplished by an entomologist living with the problem for a considerable length of time. Effective natural enemies of any insect fluctuate in abundance through the year and there are times when it might be difficult or impossible to obtain them, even where they may be accomplishing the greatest good.

To mention a few more: The koa seed worm or litchi borer *Argyroploce illepida* has a number of host plants in Hawaii, but it particularly damages litchi fruits, macadamia fruits and the seeds of *Acacia koa*. Mr. Swezey has shown that from 50 to 90 per cent of the koa seeds are often destroyed by this insect. It is known in the Oriental region and is probably well parasitized. Several parasites have been mentioned as attacking it and in southern China the litchi is said to be only lightly damaged by this worm.

The lima bean pod borer *Maruca testulalis* is a lima bean pest of major importance. It has only been known in Hawaii for about 19 years. It occurs in Indo-Malayan countries where it is not particularly destructive. It is listed as an insect of minor importance. At least one parasite is known to attack it in India. Parasites are much needed for it here.

Our most abundant cockroach is probably *Diploptera dytiscoides,* the so-called beetle roach. It is also called the cypress roach. There are times when it will mass in trees and other shrubbery or in trash on the ground by the thousands. It damages cypress trees through girdling the tender branches, which kills them and often renders the trees unsightly. Occasionally it has become so thick in the gardens at Waikiki and Kahala that residents complain. It is not a serious pest, but it can be a distinct nuisance. It is just another case of an insect living far from its natural home and hereditary enemies. It is known in Malaya, New Guinea, India and adjacent countries, where it seems to be comparatively uncommon. We should know why. It undoubtedly has natural enemies which would be useful in Hawaii, but they will probably never be found unless we search for them, since the roach bothers no one outside of these Islands.

And finally mosquitoes. What a host of natural enemies feed on mosquito larvae and pupae and how few we have in Hawaii. Our most important are the mosquito fish, but there are other enemies to be had that can operate where the fish cannot go. Many of these enemies are otherwise harmless and should be tried here. While the speaker was in Malaya during 1930 the scarcity of mosquitoes at night was immediately observed in some localities where they would be expected to be abundant. Mosquito nets covered beds almost solely for the purpose of keeping out stray malarial mosquitoes. Annoying hordes of other species were not in evidence, though small numbers of many species were always around. Natural enemies in the

form of insects which prey on the mosquito larvae and pupae were numerous in every pool or pond examined. Some of the best of these should be imported into Hawaii at frequent intervals until they become established, or at least have been given a good trial.

These are sample cases of what might be accomplished in further biological control of some of our insect pests, if we established as a first experiment a field biological laboratory in Malaya. There is every reason to believe it would be worth while. Unquestionably we need more beneficial insects and as diversification in agriculture gains headway, resulting in the extension of old crops and probable development of new ones, further insect problems are bound to arise and unless solved will surely limit the productivity of necessary food crops otherwise well adapted for culture in these Islands. The development of effective insecticidal control of some of our economic insect pests is necessary especially during emergency periods, but such procedures are expensive, especially in Hawaii and of course only temporarily effective. Without satisfactory biological control of certain insect pests some crops might be abandoned because of prohibitive costs in their control by artificial measures. The recent taro leafhopper trouble, already mentioned, is a good example.

In Dr. Walter Carter's Presidential Address to this Academy two years ago, the possibility of greatly extending our agricultural wealth through the development of many new crops or industries related to these crops was strongly indicated. The future of some will very probably depend upon the degree to which some of their insect pests, already here, can be controlled. Biologically considered, we are still isolated from the rest of the world almost as much as ever and the need for entomologists may be as great in the future as in the past. We hope, and believe, that they will meet the problems of the future in the same way, and as successfully, as they have during the past 30 or more years, and that, in the light of experience, the biological method will continue to command the faith and receive the attention that it justly deserves.

Some Observations on the Fluctuations of Moisture Content in the Sugar Cane Plant

By H. A. WADSWORTH

Although the literature of investigations on the sugar cane plant gives occasional references to the moisture contents of the plant tissue, detailed studies of daily or hourly changes in this property are conspicuously infrequent. In general the results given have been secured for special purposes and do not lend themselves to interpretation in terms of changes of moisture content with respect to time. An outstanding exception is Hartt's (2), (3), (4), (5) determinations in connection with her studies of water and cane ripening. Here the times of sampling are definitely specified and give some evidence of diurnal changes of internal moisture contents which may be of great importance in the sugar economy of the plant.

Das (1) has suggested that photosynthesis, which takes place during the period of decreased moisture content in the plant tissue, is associated with, and possibly responsible for, an increase in the percentage of recoverable sucrose in the cane plant. Observations (11) on the percentage of total sugars secured from growing cane in Field B-4, Pioneer Mill Company, indicated a significant fluctuation in this value during a 24-hour period. Although the consistently high percentages of total sugars, reported late in the afternoons when the hand refractometer was used, may be caused by an accumulation of sugar during the day, it would appear more probable that such an effect results in part from a temporary depletion of moisture in the tissues sampled. The fact that the Brix falls during the night adds support to this conclusion. Similar observations at the variety station at Hilo failed to disclose any such diurnal variations in percentages of total sugars during the 24-hour cycle. Apparently the transpirational demand at Hilo did not require a withdrawal of water from the stick with concomitant concentration of sugars.

The evident relationship between these observations upon Brix variations at Lahaina and Hilo, the reputations of the two locations for quality ratios and Das' suggestion may prove to be the turning point in our better understanding of some of the factors involved in economical sugar production particularly when irrigation is resorted to.

MOISTURE CONTENTS IN GROWING CANE

As has been suggested, Brix values within short time intervals may be assumed to be closely correlated with the moisture in the tissues sampled; a more direct measure is, of course, the actual determination of the moisture content by oven-drying procedures. Unfortunately such determinations require the destruction of the plant; consequently they are infrequently done.

Opportunities for making such determinations were available, however, at Waipio in conjunction with Experiment 104-I, the results of which have been re-

cently reported (12). The results support the conclusions drawn from the Brix studies. They are given here to complete the record.

MOISTURE PERCENTAGES ON THE WET BASIS AND DRY BASIS

Losses of water by oven drying are best reported as percentages of some specified quantity. This may be either the weight of the green tissue which is weighed into the drying tins or the weight of the oven-dried tissue remaining in the tins after exposure to the heat of the oven.

If the weight of the green tissue is used as the basis of per cent loss, the result is said to be reported on the wet basis.

If the weight of the oven-dried tissue is used as the basis of per cent loss, the result is said to be reported on the dry basis.

If T = weight of oven-dry tissue involved,

W = weight of water associated with that tissue,

then $(T + W)$ = weight of green tissue,

and $\dfrac{W}{T} \times 100 = Pd = \%$ moisture (dry basis)

$\dfrac{W}{(T + W)} \times 100 = Pw = \%$ moisture (wet basis).

It is evident that the percentage of moisture on the wet basis can never exceed 100 per cent; it is also evident that the percentage on the dry basis may approach infinity.

The relationship between Pw and Pd may be expressed:

$$Pd = \dfrac{Pw}{1 - \dfrac{Pw}{100}} \quad *$$

This equation is perfectly general. For example: a sample of cane stick weighs 120 grams when wet and loses 100 grams on oven drying. The percentage loss on drying is $\dfrac{100}{120} \times 100 = 83.3\%$ (wet basis). On the dry basis the loss is still 100 grams, but the denominator in place of being 120 grams is 20 grams, and the percentage of moisture is $\dfrac{100}{20} \times 100 = 500\%$ (dry basis).

We secure the same result by substituting in the simple equation,

$$Pd = \dfrac{83.3}{1 - 0.833} = \dfrac{83.3}{0.167} = 500\%$$

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* $\dfrac{W}{T} \times 100 = Pd$

$W = \dfrac{PdT}{100}$

$\dfrac{W}{W + T} \times 100 = Pw$

$W = \dfrac{PwT}{100 - Pw}$

$\dfrac{PdT}{100} = \dfrac{PwT}{100 - Pw}$

$Pd = \dfrac{100\,Pw}{100 - Pw} = \dfrac{Pw}{1 - \dfrac{Pw}{100}}$

It is to be noted that a moisture percentage of 500, on the oven-dry basis, means that each pound of oven-dry tissue in the stick is associated with five pounds of water.

Either of these two means of expressing moisture percentages is perfectly permissible, but their interpretation should not be confused. If a quantitative measure of the water lost from a tissue is desired, the percentage as expressed on the oven-dry basis must be used. As in other fields of physical measurements the unit selected should be the one which is to remain as nearly constant as possible. In our case this is the weight of oven-dry tissue. Although this value is not absolute and may perhaps be questionable because of increased weight through synthesis during the short periods under observation, it is to be preferred to the green-weight basis which changes with every change of moisture content.

For some purposes and within certain percentage ranges, it is unimportant which of these bases is used for expressing moisture percentages. But the differences become greater as the percentages of moisture increase. Table I indicates the relationship between these quantities as determined from the equation given above.

TABLE I

RELATIONSHIPS BETWEEN PERCENTAGES OF MOISTURE ON THE WET BASIS
(Pw) AND CORRESPONDING PERCENTAGES ON THE DRY BASIS (Pd)

Pw	Pd	Pw	Pd
0	0	70	233.0
5	5.3	80	400.0
10	11.1	85	566.0
20	25.0	90	900.0
30	42.9	95	1900.0
40	66.6	99	9900.0
50	100.0	100	Infinity
60	150.0		

By dividing each of the values given under Pd by 100 we obtain the number of grams of water associated with each gram of oven-dried tissue. For example, if the moisture percentage of a sample is 85 per cent on the wet basis, each gram of oven-dry tissue in the material sampled holds 5.66 grams of water. If the percentage of the material on the wet basis falls to 80 per cent, each gram of the material holds 4.00 grams of water. Each gram of the material has lost 1.66 grams of water while its moisture percentage on the wet basis falls from 85 per cent to 80 per cent. These ratios hold, of course, whether the units be grams, pounds or tons. In view of the large amount of dry material in a cane field and the high moisture percentages on the wet basis, it would appear that water from this source might contribute significantly to the daily needs of the crop. When adequate soil moisture is available, we would expect a restoration of moisture content in the tissue during the night with a falling off in the rate of loss by transpiration. Apparently we had some such effect with sugar cane at Pioneer Mill Company.

Diurnal Moisture Fluctuations in Sugar Cane at Waipio:

Studies directed toward the determinations of the actual changes in moisture content in sugar cane growing in the field were begun at Waipio in October 1940.

The first test was planned to gain a measure of the variability of the material available for random sampling. Cane from Field 28, variety H 109, age 12 months, was used.

Two lots of samples were taken. One of these taken at 2:00 p. m. on October 25 was supposed to represent the moisture content in the cane when the withdrawal of water from the tissue was advanced but possibly not completed. Another set of similar samples was taken at 6:00 a. m. on the following day. Supposedly the moisture deficiency impressed upon the plant by rapid transpiration during the day of October 25 would have been eliminated during the night. It is believed that the soil moisture was above the permanent wilting percentage at the time.

Fifteen sticks were cut close to the ground at each time of sampling. Samples of the dry-leaf cane, the leaf sheaths and the growing points were quickly secured, weighed to the nearest 0.01 gram in tared cans and dried to constant weight at 85° C.

Samples for the leaf sheaths included material from the sheath associated with the last visible dewlap and from the three sheaths immediately below it. The growing point was removed from its wrapping of succulent material before weighing. These samples were about one inch long.

All samples were treated separately. The averages and their probable errors are listed in Table II.

TABLE II.

AVERAGE MOISTURE CONTENTS IN PER CENT (DRY BASIS) OF SUGAR CANE
STRUCTURES COLLECTED AT 2:00 P. M. OCTOBER 25 AND 6:00 A. M.
OCTOBER 26, 1940

	Morning Oct. 26	Afternoon Oct. 25
Growing Points	962 ± 12	871 ± 19
Sheaths	437 ± 8	390 ± 7
Millable Stick	416 ± 7	385 ± 5

Although these differences are not large, they may be considered as significant and are in the direction anticipated.

Such evidence as that given in Table II suggests a cyclic action characterized by high moisture contents before daybreak and low moisture contents late in the afternoon or early evening. An attempt to explore this possibility was made in a sequence of samples secured from the same area at three-hour intervals between 9:00 a. m. November 22, 1940 and 6:00 a. m. November 23, 1940. Limitations of equipment made it necessary to reduce the number of samples to four sticks taken at random at each time of sampling. The variability noted at the time of the first sampling, and reported in Table II, tended to obscure the details of the suggested cycle. Results are given in Table III for the sake of completeness of the record. Average values alone are reported; the limited number of samples taken precludes any satisfactory measure of variability. Apparently the number of samples was inadequate.

TABLE III

MOISTURE CONTENTS OF CANE STRUCTURES AT VARIOUS TIMES
OF THE DAY (DRY BASIS)

Hour	Growing point	Sheath	Millable stick
9 a. m.	890	366	393
Noon	916	451	408
3 p. m.	832	397	342
6 p. m.	960	444	393
9 p. m.	950	386	370
Midnight	923	406	376
3 a. m.	991	448	395
6 a. m.	1065	471	375

Apparently the diurnal cycle of moisture contents, if it exists, could only be plotted in detail if many more samples were taken than were available during the test reported in Table III. Moreover, if this diurnal sequence is a result of transpirational demands in excess of the possible rate of supply by the roots, its appearance might not be marked in November.

An additional series of determinations of moisture contents in growing points was made on November 4 and 5, 1940. For this test sticks were cut from a stand of two-year-old cane which had been trained to stand erect at the Keeaumoku Street Station. The canes were about 20 feet tall. Ten sticks were cut and growing points removed at 4:30 p. m. on November 4; a similar collection was made at 6:00 a. m. on the following morning. Although the average values for the moisture contents were numerically different in the sense that the afternoon samples were drier than those secured in the morning, the difference was not statistically significant. The average values were as follows:

4 p. m. Samples .... $673 \pm 33\%$ (Dry Basis)
6 a. m. Samples .... $714 \pm 36\%$ (Dry Basis)

It is to be noted that these average values of moisture content in growing points are associated with evidence of high variability. The same characteristic was noted in the results from the first series of growing-point samples at Waipio, reported in Table II. In searching for a cause for this great variability, it was observed that low values for the percentages of moisture content were associated with samples of high weight after oven drying. The correlation coefficient between moisture percentage and oven-dry weight at the time of the morning sample was -0.82 ± 0.11. The correlation coefficient between the same variables for the afternoon sample was -0.88 ± 0.08. Such high degrees of correlation are at least suggestive.

Since the amount of tissue taken was not uniform, it seems probable that the heavier samples, after oven drying, were originally longer and included more relatively dry tissue below the actual tip. When the points representing these two series of variables are plotted and fitted with straight lines, both lines intersect the zero weight axis at a percentage of about 1000. Apparently the tip of the growing point carries almost 10 grams of water for every gram of oven-dried tissue. And too, this value seems to be independent of the time of day in contrast to the evidence of day-time desiccation in other tissues.

This single observation is inadequate as a basis for generalities. However, it

might be reasoned that there is evidence that a distinct gradient in moisture content exists in the top of the cane stick. Moreover, it might appear that a constant moisture was maintained in the apical meristem if possible, even if other tissues suffered partial desiccation during the day.

Moisture Determination by Other Workers:

In an early report on "Water and Cane Ripening" Hartt (2) gives moisture percentages for blades, sheaths and green-leaf cane. Half of the plants in the study were suffering from inadequate soil moisture; half had an adequate supply. Each of these lots was divided again. One half of each had been held in the dark until the time of sampling; the other half was removed to the greenhouse and had experienced seven hours of sunlight after a long period in the dark. The four series were called "Dark dry," "Dark wet," "Light dry" and "Light wet."

Moisture percentages as reported are given in Table IV.

TABLE IV

MOISTURE PERCENTAGES IN CANE PLANTS SUPPLIED WITH OR
DEPRIVED OF WATER. (AFTER HARTT [2])

	Blades	Sheaths	Green-leaf cane
Dark dry	67.89	79.63	84.36
Dark wet	70.72	85.21	88.52
Light dry	66.64	76.30	84.16
Light wet	69.57	84.20	87.83

The percentages given in Table IV are on the wet basis. To indicate the actual amount of water involved, these percentages should be changed to the corresponding values on the dry basis. This is done in Table V.

TABLE V

MOISTURE PERCENTAGES IN CANE PLANTS SUPPLIED WITH OR
DEPRIVED OF WATER (DRY BASIS)

	Blades	Sheaths	Green-leaf cane
Dark dry	211	392	539
Dark wet	242	577	772
Light dry	200	321	531
Light wet	228	536	721

Since the percentages reported in Table V are given on the dry basis, differences in values represent masses of water associated with unit masses of dry tissue. Thus sheaths on dry plants in the dark held 3.92 grams of water per gram of dry matter. After 7 hours exposure to light each gram of dry tissue held 3.21 grams of water. Apparently 0.71 gram of water had been withdrawn from each gram of this tissue during the seven hours. During the same interval only 0.08 gram had been lost from each gram of green-leaf cane.

The weights of water lost from these tissues and others during the seven hours of exposure to evaporating conditions in the greenhouse are given in Table VI.

TABLE VI

LOSS OF WATER IN GRAMS PER GRAM OF OVEN-DRIED TISSUE DURING
7 HOURS OF GREENHOUSE EXPOSURE

	Blades	Sheaths	Green cane
High Soil Moisture	0.14	0.41	0.51
Low Soil Moisture	0.11	0.71	0.08

Apparently during periods of readily available soil moisture the green cane and sheaths lost most heavily when the plants were exposed to the environment of the greenhouse. In the case of the dry series the major contribution was made by the leaf sheaths.

Similar studies were reported by Hartt in 1936 (3), (4) and 1939 (5). Results were comparable to those reported above. In all cases there was a marked fluctuation of moisture content in the sampled parts during the 24-hour period involved.

In discussion of the variations of moisture content within the plant tissues in one of these reports (4) the statement is made that "It would seem that the moisture content of the sheaths is affected by the time of day less than is the moisture content of the blades." The sheaths in one case vary from 79 per cent to 81 per per cent (wet basis); the blades from 67 per cent to 70 per cent (wet basis). Here we have a loss of 3 per cent from the blades and 2 per cent from the sheaths. If these percentages are translated into figures on the dry basis, which alone permits comparison, the sheaths vary from 377 per cent to 425 per cent, the blades from 202 per cent to 233 per cent. Apparently each gram of oven-dried material in the sheaths contributed 0.48 gram of water during the desiccation while the blades contributed 0.31 gram of water per gram of oven-dried material.

Although the total mass of sheath tissue associated with a cane plant is small in comparison with the total, such tissue seems to have an outstanding capacity to acquire water when available and to supply it upon demand.

Further evidence (10) of the delicate relationship between leaf sheaths and soil moisture contents comes from a study of the length of sheaths produced on the Waipio experiment (12) which has been mentioned. Frequent collections of the sheaths produced under the various treatments demonstrated that sheaths were definitely shorter when produced under a history of repeated soil moisture deficiency, than when produced under such frequent irrigation that moisture was always readily available. This difference tended to disappear as the crop became older possibly because of increased length of stick below the green top. One explanation for the shorter length of sheaths from plants which had experienced frequent periods of drought is to assume that the desiccation of this tissue was so frequent and so intense that maximum length could not be secured before structural maturity was attained.

Subsequent observations upon the lengths of the cane joints formed under the several treatments gave analogous results. Joints formed in the first season under conditions of intermittent soil-moisture deficiency were significantly shorter than joints formed at the same time under conditions of adequate soil moisture. Here too the difference tended to disappear as the crop aged. The average lengths of joints formed on the two extreme treatments during the second season showed no significant difference.

The Significance of the Amounts of Water Involved:

As has been suggested small differences in moisture content when expressed as percentage on the wet basis become significant when expressed on the dry basis which alone is permissible if comparisons of actual amounts of water are desired.

Thus a decrease of percentage of moisture from 82 per cent to 80 per cent (wet basis) means that each gram of oven-dried tissue has surrendered 0.55 gram of water during this desiccation. What this amounts to in the water economy of the plant depends, of course, upon the amount of such tissue involved. One method of determining the amount would be to oven dry the entire plant. Another and more practical way would be to compute it.

At Waipio in 1930, plants grown in tanks under rigid irrigation control (6) had produced about 40 pounds of millable sticks at an age of 15 months. If it be assumed that this is the weight at sunrise when the moisture percentage is maximum or 82 per cent (wet basis) the amount of moisture in the cane sticks is 0.82×40 or 32.8 pounds. Apparently there are 7.2 pounds of oven-dry material in the cane.

The moisture percentage on the wet basis now falls to 80 per cent. It is not permissible to multiply 40 by 0.80 in this case since the weight of 40 pounds is associated with a moisture percentage of 82 (wet basis), not 80 per cent. We may however resort to our relationship between percentage expression on the two different bases. Table II indicates that at 80 per cent moisture (wet basis) each pound of oven-dry tissue is associated with 4 pounds of water. From our analysis we have 7.2 pounds of oven-dry material, exclusive of the small amount synthesized between the times of sampling. Consequently the number of pounds of water in the cane at the second sampling is $7.2 \times 4 = 28.8$ pounds. Evidently four pounds of water have been lost from the mature cane in the stool between the hours of sampling.

This cannot be considered as insignificant in the plant's water economy since by gravimetric determinations the daily losses of water from the soil-plant system were normally about ten pounds and rarely exceeded 15 pounds. It is to be noted that the procedure used for measuring daily loss at Waipio (6) failed to differentiate between water lost from the soil and water lost from the plant.

Moreover, the analysis given above fails to recognize contributions from sheaths and green tops which contribute to the daily demand in greater measure, pound for pound, than the mature sticks.

DISCUSSION

There is no thought in this argument that soil moisture is unimportant in considerations of the plant's well-being. The thought is that water may be withdrawn from the transpiring surfaces at a rate greater than the rate of supply by the roots even at high soil moisture contents.

Apparently if the soil moisture is readily available, temporary moisture deficiencies within the plant, caused by rapid transpiration during the day, are rectified by additions of moisture by the roots during the night. The plant has been restored to its normal turgor by sunrise and suffers another period of temporary depletion during the next day if environmental factors are sufficiently intense. If, however, soil moisture is depleted and no longer available at an adequate rate the plant would, presumably, enter a period of intense transpiration demand at a re-

duced moisture level. Further desiccation of tissue would result. Recharging of the tissues by slow replacement by the roots at night would be progressively inadequate. Ultimately the plant would die.

There is little evidence that such minor diurnal desiccations as those suggested above entail economic losses of recoverable sugar. In fact cane in high-producing areas in which high temperatures and intense light are common, such as certain sites near Lahaina, Puunene, Ewa and Kekaha undoubtedly suffer diurnal fluctuations of moisture greater than those reported above.

Nor have we been able to curtail seriously the economic production of sugar (7), (12) by impressing reasonable periods of soil moisture deficiency upon plants grown in carefully controlled experiments. In such treatments the moisture content of the plant must have been lowered during the purposely imposed periods of soil moisture deficiency, although we have no experimental data to demonstrate this deficiency.

In these experiments it was assumed that moisture from the soil was "not readily available" when the soil moisture fell below the permanent wilting percentage. The phrase "not readily available" is not to be interpreted too literally. There is of course some continuing supply from the soil, although at a reduced rate after this arbitrary percentage has been passed. Moreover, from a study of the shape of the soil moisture-surface force curve (9) it would appear that the percentage range of slowly available moisture in Hawaiian soils is broader than with soils on the mainland which have been widely studied. As was reported many years ago (8) "In any event there seems to be a critical soil-moisture content with cane, as in other plants, below which plants function differently than when soil-moisture is more abundant. And this critical soil-moisture constant for cane is numerically close to the wilting coefficient for other plants. Apparently, if the term 'wilting coefficient' is to be applied to soils of interest to sugar cane growers, the term must be redefined or used with reservation."

It is to be remembered too that soil samples, taken for irrigation control of sugar cane, are secured by sampling the first two or two and a half feet of the soil profiles. We have no assurance that roots do not exist in sufficient concentration in lower depths to supply partial turgor to the plant for some time after the soil moisture in the sampled horizon has fallen to our arbitrary limit. The fact remains however that the permanent wilting percentage is a soil moisture content of definite physical significance; its physiological significance is more evident with other plants than with sugar cane.

An Application to Irrigation Control

The argument given above is based upon too little experimental evidence to do more than to suggest a general pattern of internal water relations. More evidence is necessary before these preliminary findings can be applied with any confidence to irrigation control.

But if the general pattern is correct certain possibilities present themselves. One of them is to time the irrigations in such a way that the moisture content in the leaf sheaths before sunrise is never permitted to fall below a critical value. What this value is we do not know but we should be able to identify it so that it may be used to indicate the advent of progressive, uneconomic desiccation of the top of the

plant as a result of soil moisture deficiency. The practical difficulty is that an impossibly great number of plants would be destroyed in the process. Perhaps some function of the many suggested measurements of environment can be used after experimental methods determine the relationship between these measurements and internal moisture relationships.

Another possibility involves observations upon the rate of elongation of young leaves in the top. Repeated observations indicate that the cluster of young leaves crowning the growing point continues to grow at a uniform rate long after the conventional dewlap measurement shows definite retardation. It is possible of course that the growth in this succulent tissue is retarded only when permanent damage has been done to the delicate tissue in the apical meristem. But there are about five leaves between this cluster and the leaf associated with the last visible dewlap. Perhaps one of these will give evidence of incipient moisture deficiency within the plant before an economic loss of growing time and sugar formation is experienced.

If moisture content is a function of Brix value over short periods, refractometer readings of critical tissues might give evidence of significant moisture deficiencies within the plant before damage had been done.

It is recognized that these suggestions are only pertinent if the general pattern of the internal moisture history of the cane plant is of the order that has been suggested. This has not, as yet, been adequately demonstrated although much evidence points toward this interpretation.

In view of the many variables involved it would appear that the best criterion for the need of irrigation will be provided by the plant itself. This criterion can only be identified by an exhaustive study of the internal moisture relationships within the plant.

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Potash Requirements For Sugar Cane

By R. J. Borden

The sugar cane plant is a great lover of potash and, if it has the opportunity to do so, will consume large quantities of this mineral nutrient. This fact gives rise to the natural question of whether in order to function efficiently the cane plant needs as much potash as it will take up. And a logical question which then suggests itself is, "Since the cane plant takes out of a soil such a large amount of potash, are we in danger of depleting the available supply of natural soil potash if we do not fully return that which is taken up by the crop?"

The total potash supply as found in Hawaiian soils is not excessively high when compared with many mainland soils. Van Brocklin (7) has summarized the data from many total potash analyses made at the Experiment Station, and these indicate few soils with less than 12,000 pounds of total potash and many above 25,000 pounds per acre-foot. Furthermore much of this potash is unavailable to crops of the immediate future and, since there is always some doubt that our methods of ascertaining available potash for sugar cane actually do measure the amounts available, our interpretations of potash availability and estimates of potash fertilizer needed are somewhat complicated.

The depletion of soil fertility by removing essential growth elements in excess of what are returned by residues, manures, and fertilizers has been the theme of many agricultural sermons. It is of very particular concern to our planters who grow such heavy tonnages of cane on the same land year after year.

Maxwell (4) has reported the following amounts of K_2O removed per acre by two cane varieties:

Variety	Tons/acre millable cane	Dry wgt. (tons/acre) Cane	Dry wgt. (tons/acre) Leaves	Lbs. K_2O/acre in dry wgt. Cane	Lbs. K_2O/acre in dry wgt. Leaves	Total lbs. K_2O/acre removed
Rose Bamboo	89.36	23.82	26.40	258	882	1140
Lahaina	77.20	22.20	26.31	121	807	928

Hence for each ton of millable cane, Rose Bamboo took up from the soil 12.8 pounds of K_2O, 77 per cent of which was in the leaves and only 23 per cent or 2.9 pounds of K_2O in each ton of the stalks, whereas Lahaina, which took up 12.0 pounds K_2O for each ton of millable cane which this variety produced, had 87 per cent of it in the leaves and only 13 per cent or 1.6 pounds per ton in the stalks.

From one of Stewart's reports (6) we have compiled the following figures from weights and potash analyses of mature H 109 cane from 3 sources:

Source	Net cane tons/acre	Tons/acre Tops and trash	Tons/acre Bagasse and mixed juice	Lbs. K_2O/acre Tops and trash	Lbs. K_2O/acre Bagasse and mixed juice	Total lbs. K_2O/acre removed
Ewa 26B	76.2	19.8	103.3	144.9	179.2	324.1
Ewa 20B	117.7	19.2	159.2	153.8	309.9	463.7
Oahu 10A	102.2	22.3	146.7	201.3	208.6	409.9
Average	98.7	20.4	136.4	166.7	232.6	399.2

These potash figures are considerably lower than those reported by Maxwell for the two different cane varieties which he studied. From them we would estimate that this H 109 cane has taken up only 4.1 pounds of K_2O to produce each ton of millable cane, and that 42 per cent of this potash uptake was in the tops and trash and 58 per cent or 2.4 pounds in each ton of the stalks.

From another study, Stewart presents many analyses from different treatments of H 109 cane which was harvested at different ages at Oahu Sugar Company. We have averaged the potash analyses from these treatments to estimate the number of pounds of potash removed for each ton of millable cane that was secured:

AVERAGE POUNDS K_2O PER TON MILLABLE CANE HARVESTED

Source	At 5 mos.	At 8 mos.	At 12 mos.	At 17 mos.	At 24 mos.
In millable cane only..........	6.31	3.37	2.49	2.15	2.16
In entire plant................	21.47	13.65	6.51	5.63	4.08

Ayres (1) summarizes studies made on H 109 cane at Waipio which indicate that in a long growth period of 24 months, and for a final yield of 99 tons of millable cane, the potash found in the total growth of millable and dead cane, dry and green leaves and tops, amounted to 560 pounds or the equivalent of 5.6 pounds for each ton of cane milled, whereas at the age of 12 months when 52 tons of millable cane had been grown, this crop carried a total of 340 pounds of potash, which is equivalent to an uptake of 7.5 pounds of potash for each ton of millable cane cut at this younger age.

Furthermore, Ayres reports (3) that the percentage of potash varies considerably in the dry matter of the stalks and the green and dead leaves. For example, for his H 109 cane harvested at Makiki at the age of 12 months, he finds .55 per cent potash in the dry matter of the stalks as compared with 2.22 per cent and 1.08 per cent in the dry matter of the green and dead leaves respectively.

In another study (2), Ayres found the percentages of K_2O in the dry matter of 5 cane varieties grown in an identical soil medium to be as follows:

	POJ 2878	Badila	H 109	D 1135	Yel. Cal.
% K_2O in stalks............	1.74	1.16	1.06	1.45	1.34
% K_2O in tops	3.19	2.95	2.98	2.81	2.50

Moir (5) reports percentage figures for potash in two cane varieties as follows:

	H 109	D 1135
% K_2O in stalks.................................	.30	.53
% K_2O in leaves and tops	3.19	2.08

Calculations made from other data show that 38 per cent of the total potash found in an H 109 cane crop at 12 months was located in the stalks only. The actual quantity of potash found in H 109 stalks at 12 months by Ayres was 45 per cent of the total amount found in both the stalks and leaves.

However, on the basis of results from six studies which Ayres has summarized (1), he estimates that for each ton of millable stalks alone, in a 2-year crop taken to the mill, there is approximately only two pounds of potash. He believes that this represents the net loss of potash from the field soil, since the remainder contained in the trash and tops stays in the field, and is not materially changed when the trash is burned.

First Study with POJ 2878:

Previous investigations of the amounts of potash contained in sugar cane crops have been generally concerned with total potash found in the crops harvested, and the inference drawn has been that the results have indicated the potash requirements. In few, if any, of these studies that have been made to show the amount of potash taken out of the soil by the cane crop, have variables been present or introduced which would enable one to determine whether potash uptake correctly indicates the potash needs for optimum yields. Hence in an effort to learn more about how this potash uptake may be related to the potash requirements of sugar cane we have now completed two skirmish tests which were planned with this objective in mind.

In the first of these we used the cane variety POJ 2878 and, since indications of heavy tasseling appeared in October, we grew the crop for only nine months, under controlled conditions in Mitscherlich pots each filled with 4,500 grams of Manoa soil. The analysis of this soil by R.C.M. gave the following results:

Ammonia nitrogen	$= .0005\%$	Available K_2O	$= .0032\%$
Nitrate nitrogen	$= .0004\%$	Available CaO	$= .014\%$
Available P_2O_5	$= .0008\%$	pH	$= 4.7$
P_2O_5 fixation	$= 90{-}75{-}40$	(Replaceable $K_2O^* = .0106\%$)

* % Replaceable K_2O = % K_2O by R.C.M. $\times 3.3$.

At the time of potting all pots were given liberal allotments of phosphate and nitrogen fertilizers, and supplementary nitrogen applications were also made later on. Two single-eye cuttings were planted in each pot in January, and the following 9 differential applications of potash were added at this time.

Treatment No.	Amt. of K_2O supplied	Treatment No.	Amt. of K_2O supplied	Treatment No.	Amt. of K_2O supplied
1	None*	4	.750 gm.	7	3.0 gm.
2	None	5	1.5 gm.	8	4.5 gm.
3	.375 gm.	6	2.25 gm.	9	6.0 gm.

* In Treatment No. 1, the soil was diluted with three-fourths silica sand.

The crop started late in January got off to a very slow start, and because of tasseling it was harvested in October. Cane stalk lengths, diameters, weights, and juice samples were secured, as well as composite samples of plant material (except roots). The potash analyses of plant material were all made by our Chemistry Department. The data which have now been summarized in Tables I and II bring out some interesting facts.

Inspection of Table I will reveal that the optimum yield of cane and sugar probably belongs to Treatment No. 7. A study of Table II shows that Treatment No. 7 was supplied with 3.475 grams of available potash, and that 2.932 grams of this were recovered in the total dry weight that was harvested. This is considerably less than the amounts of potash which were taken up by Treatment Nos. 8 and 9, and indicates a luxury uptake from these two treatments since their resultant cane and sugar yields had not followed their greater potash uptake at the time of harvest. Fig. 1 shows these same relationships, and also an indication that

the total dry weight may have responded more directly to the higher amounts of potash supplied than the millable cane and recoverable sugar; this is undoubtedly because of the high ratio of tops to millable cane in a crop that is only nine months old.
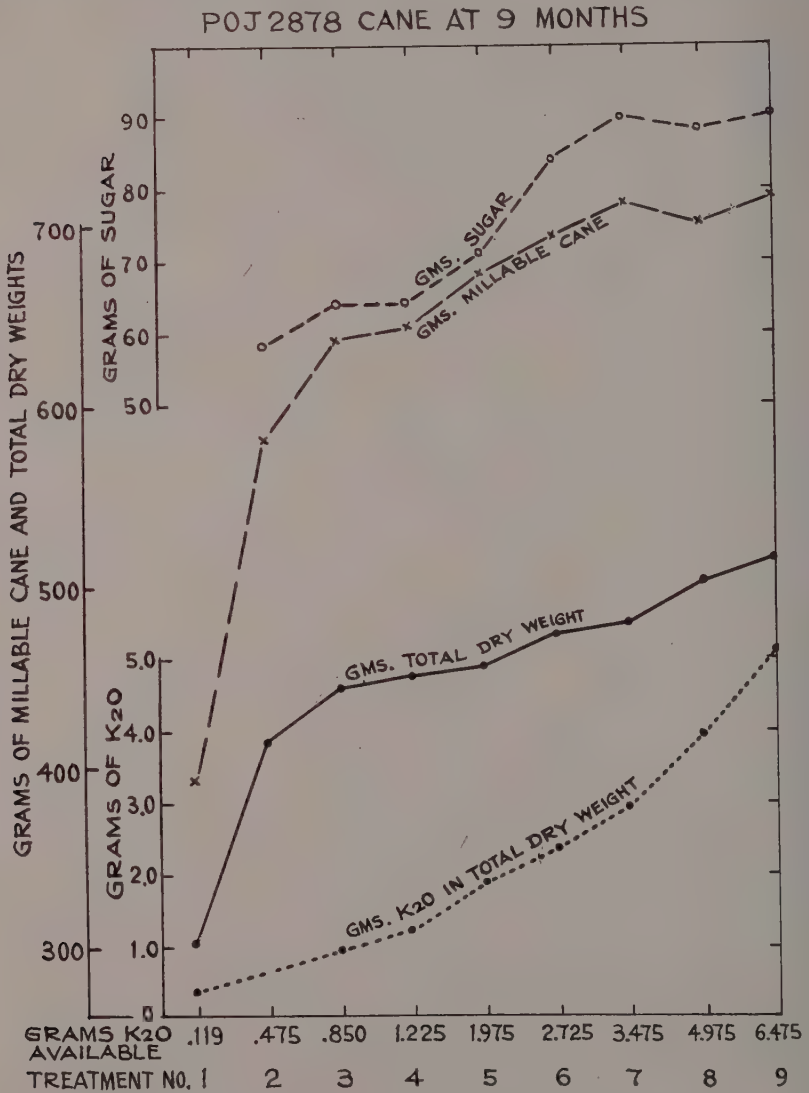

POJ 2878 CANE AT 9 MONTHS

Fig. 1

The data associated with Treatment No. 7 can now furnish us with an idea of the amount of potash that was used for the optimum yield and, if we can interpret them correctly, they should also give us a guide which could be used to design a policy for potash fertilization that would furnish an adequate amount for cane crops and at the same time maintain the soil potash supply.

TABLE I

SUMMARY OF YIELDS VARIETY POJ 2878—AGE 9 MONTHS

No.	Gms. K_2O added	Available[1] potash (gms.)	Stalk length (cm.)	Stalk[4] diameter (cm.)	Cane[2] green wgt. (gms.)	Y%C[3]	Pur.[3]	Sugar (gms.)
1	0	.119	85	1.76	394	*	*	*
2	0	.475	88	2.07	581	9.8	76.6	57
3	.375	.850	87	2.16	638	10.1	76.4	64
4	.750	1.225	86	2.20	643	9.9	77.7	64
5	1.5	1.975	88	2.25	676	10.5	81.7	71
6	2.25	2.725	86	2.24	695	12.1	83.0	84
7	3.0	3.475	87	2.36	713	12.7	86.4	90
8	4.5	4.975	84	2.33	701	12.5	87.4	88
9	6.0	6.475	83	2.40	717	12.5	85.8	90

* Crusher juice too dark to secure readings.
[1] Replaceable K_2O plus K_2O added in fertilizer.
[2] Average of 4 replicates. Difference needed for significance = 65 grams.
[3] From composited crusher juice sample.
[4] Stalk diameter taken at uppermost dry-leaf internode.

TABLE II

POTASH UPTAKE BY VARIETY POJ 2878—AGE 9 MONTHS

Treat. No.	Gms. replaceable K_2O in soil	Gms. K_2O added in fert.	Avail.[1] potash (gms.)	Total dry wgt.[2] harv. (gms.)	% K_2O[3] in dry wgt. samples	Grams K_2O in total dry wgt.	% of[4] avail. K_2O recovered	% K_2O in soil after harvest
1	.119	0	.119	302	.123	.371	340	.0008
2	.475	0	.475	416	.165	.687	145	.0008—
3	.475	.375	.850	442	.220	.973	114	.0008—
4	.475	.750	1.225	450	.267	1.202	98	.0008—
5	.475	1.500	1.975	456	.412	1.879	95	.0008—
6	.475	2.250	2.725	473	.494	2.337	86	.0008—
7	.475	3.000	3.475	479	.612	2.932	84	.0008
8	.475	4.500	4.975	501	.782	3.915	79	.0008—
9	.475	6.000	6.475	516	.982	5.064	78	.0008

[1] Replaceable K_2O plus K_2O added from fertilizer.
[2] Average of 4 replicates. Difference needed for significance = 35 gms.
[3] From composited sample of all dried leaves, green leaves, tops and millable cane (no roots).
[4] Exclusive of roots.

We find that when the optimum yield of 713 grams of millable cane (and 90 grams of sugar) was produced, 2.932 grams of potash were taken up in the stalks and leaves. This has been estimated* to be equivalent to about 97 pounds of K_2O per acre for a crop nine months old which had a rather slow start and development. The millable cane in this crop at this age is estimated at only about

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* $\dfrac{2.932 \text{ gms.}}{2 \text{ stalks}}$ = 1.466 grams per stalk $\times$ 30,000 stalks per acre.

13 T.C.A.*; hence for each ton of millable cane that was produced at nine months, there was a potash requirement of 7½ pounds per ton; this figure is similar to that which Ayres found was taken up in growing a ton of H 109 millable cane to the age of 12 months, i.e., 7.5 pounds.

According to our analysis of this soil, we would expect that an acre to a depth of only 6 inches would furnish 135 pounds of available potash if the cane roots were able to get it all out. In spite of the fact that the cane roots very completely permeated the soil mass in the small pots in which this cane was grown, they were apparently not able to get enough of this potash in nine months, for the optimum yield was not obtained until more potash (3.0 grams) was added from the fertilizer. In fact it would appear that the plants in Treatments Nos. 7, 8, and 9 got very little of this soil supply of K_2O which we have called "available," for the total recovery in the leaves and stalks was slightly less than the actual amounts supplied by the potash fertilizer alone. On the other hand, however, where no or only a very inadequate amount of potash fertilizer was added, we have an indication that considerably more potash was recovered in the plant material harvested than we had estimated as "available K_2O."

Treatment No. 7 which produced 479 grams of total dry weight took up 2.932 grams of potash. This total dry weight at 9 months of age consisted of 60 per cent trash and tops and 40 per cent millable stalks. The stalks had a moisture content of 273 per cent (dry-weight basis)—thus an equivalent green weight of 713 grams. Separate determinations of potash in these two components of the cane sample were not made, hence we must estimate them from other information that has been collected.

A study of Moir's data (5) shows that for H 109 cane the total dry weight consisted of 64 per cent tops and trash and 36 per cent stalks at the age of 8 months, and that this ratio had changed to 34 per cent tops and trash and 66 per cent cane stalks at 12 months. At the 8-month harvest only 25 per cent of the total potash was found in the stalks, whereas at 12 months this figure had become 38 per cent.

Assuming that the trash and tops are to be left in the field and will release their potash for the subsequent crop, our obligation to nature becomes one of returning that which is taken out of the field in the stalks. We might estimate this to be about 30 per cent of the total uptake by cane which is cut at 9 months. Hence 30 per cent of 2.932 grams or only .88 grams would need to be supplied for each 713 grams of these stalks which were milled; this would be equivalent to 2.5 pounds of K_2O per ton of young POJ 2878 stalks taken to the mill. Considerably more than this amount would be needed if much of the trash and tops are hauled away with the stalks.

For cane older than 9 months, we might postulate that the K_2O requirement per ton of millable stalks will be less than for young cane. Ayres' figures have indicated that the potash uptake by 24-month H 109 cane indicated a K_2O requirement that was about one third less for each ton of millable cane than for a 12-month crop (5.6 pounds vs. 7.5 pounds). Moir's data show that whereas 24 tons of cane stalks (only) cut at 8 months carried 80 pounds of K_2O or 3.3

* $\dfrac{713 \text{ gms.}}{2 \text{ stalks}} = 357$ grams per stalk × 30,000 stalks per acre.

pounds of K_2O per ton, 50 tons at 12 months carried 125 pounds or 2.5 pounds of K_2O per ton, and 106 tons of millable stalks harvested at 24 months contained 244 pounds or 2.3 pounds of K_2O per ton. Since a 2-year crop at harvest does not consist entirely of stalks that are *all* 2 years old, but may contain many that are 1 year old or less, perhaps our estimate for potash to be supplied from fertilizer should be based on the ratio of the old-to-the-young stalks harvested. For instance, 60 per cent of the POJ 2878 stalks in a 22-month old 70-ton crop might be of first-season origin, and 40 per cent be less than 12 months old. Our reasoning then would be something like this: The 40 per cent of this 70-ton crop or 28 tons of young stalks would take away potash at the rate of 2.5 pounds per ton— i.e., 70 pounds, whereas the potash removed in the 60 per cent or 42 tons would be at a somewhat lower amount per ton—perhaps at 1.7 pounds per ton or 71 pounds. Thus a total of 141 pounds of K_2O should balance the potash losses as far as such a crop is concerned, and maintain an adequate supply for the next crop— provided none of it is lost.

Discussion:

The very immature age (9 months) at which this POJ 2878 cane was harvested must be remembered in connection with the indication that 2.5 pounds of K_2O should be sufficient to replace the potash taken away from the field in each ton of millable cane stalks only; for older cane we are quite confident that this figure will be somewhat less.

Apparently the results we have secured also indicate that there will be a somewhat greater uptake, for each ton of millable cane harvested, by short than by long crops; this will need consideration in planning amounts of potash to be used on short crops.

In the short 9-month growth period from those treatments which received the heavier application of potash fertilizer, we did not succeed in recovering all of the potash which we had estimated to be available—or even all that which had been applied in the fertilizer. Moreover we did not identify this "lost" potash in the soil after harvest, although it is quite likely that some would have been found in the roots and stubble if these had been weighed and analyzed. Since our technique precluded any actual losses of potash, we shall have to assume that some of the applied potash was changed over and existed in the soil in some form other than that which our chemical analysis identified as available potash. Support to such an assumption is offered by the fact that in Treatments 1, 2, and 3 we note an actual recovery of more K_2O than had been identified as being available when the crop was planted. Apparently therefore, when cane is grown on an available-potash-deficient soil and inadequately fertilized with potash, it has the power of drawing quite heavily not only on the replaceable but also on some form of non-replaceable potash in our soils. And on these same soils, if the applications of soluble potash fertilizer have been in excess of that which the plant has had time to absorb, such potash may become a part of the replaceable and also of this non-replaceable form which is apparently available for sugar cane.

Second Study with H 109 and 31–1389 Canes:

In our second study (Project A–105—94.1) which sought to determine the

amount of potash absorbed by the cane plant per unit of (a) dry matter, and (b) millable cane, and to estimate the amount that leaves the field and that which is left, we used two different cane varieties—H 109 and 31–1389—and grew the crop for a full 12-month period in Mitscherlich pots filled with 4,500 grams of Manoa soil. This particular soil had the following analysis by R.C.M. at the time of planting:

Ammonia nitrogen	= .0008%	Available K_2O	= .0028%
Nitrate nitrogen	= nil	pH	= 4.6
Available P_2O_5	= .0006%	(Replaceable K_2O =	.0092%)

Ample amounts of nitrogen and phosphate were supplied and all conditions except the potash fertilization were made uniform. Two single-eye cuttings were planted in each container in November, after the following 8 differential amounts of potash had been mixed into the soil:

Treatment No.	Amount of K_2O supplied	Treatment No.	Amount of K_2O supplied
1	.... None	5	.... 4.5 gms.
2	.... .75 gm.	6	.... 6.0 "
3	.... 1.5 gms.	7	.... 7.5 "
4	.... 3.0 "	8	.... 9.0 "

The crop was harvested at the age of one year, being segregated so that weights and analyses would be available from (a) trash* and tops, (b) millable cane† (bagasse and crusher juice), and (c) roots. Thus we have a much more complete story than we had from our first study. The complete data are given in Tables III to VIII inclusive, and in Figs. 2 and 3 some of these data are shown graphically.

TABLE III

SUMMARY OF YIELDS

VARIETY H 109—12 MONTHS OF AGE

(Averages of 3 Pots)

Treatment No.		Gms. K_2O added	Stalk diameter (inches)	Cane (lbs.)	Brix	Purity	Y%C	Sugar (lbs.)
1	....	0	1.02	3.55	14.4	79.6	8.01	.28
2	....	.75	1.05	3.93	15.5	81.9	9.07	.36
3	....	1.5	1.08	4.20	15.3	80.6	8.72	.37
4	....	3.0	1.20	4.68	16.8	85.8	10.70	.50
5	....	4.5	1.16	4.88	16.4	84.9	10.25	.50
6	....	6.0	1.27	4.65	16.5	86.7	10.65	.49
7	....	7.5	1.18	4.80	16.9	85.2	10.54	.50
8	....	9.0	1.18	4.38	17.3	88.6	11.53	.54
Minimum difference required for significance			.10	.65	1.1	3.1	1.59	.11

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* Including that which accumulated throughout the entire growing period.
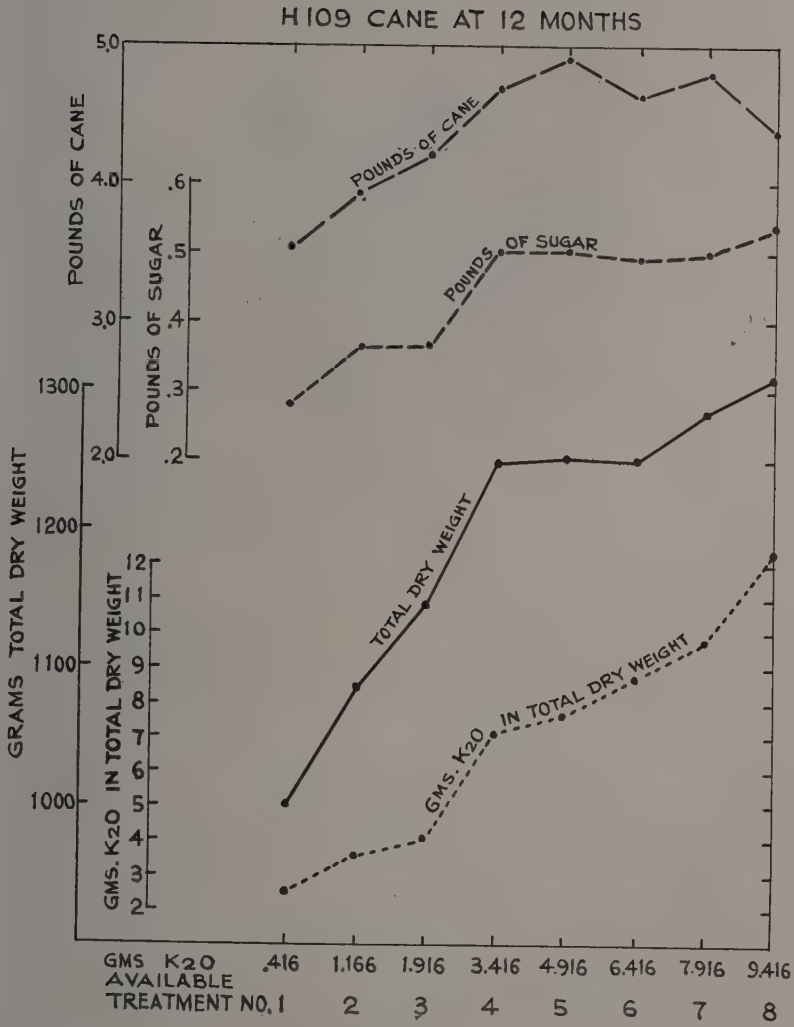
† All stalks were topped at their growing point.
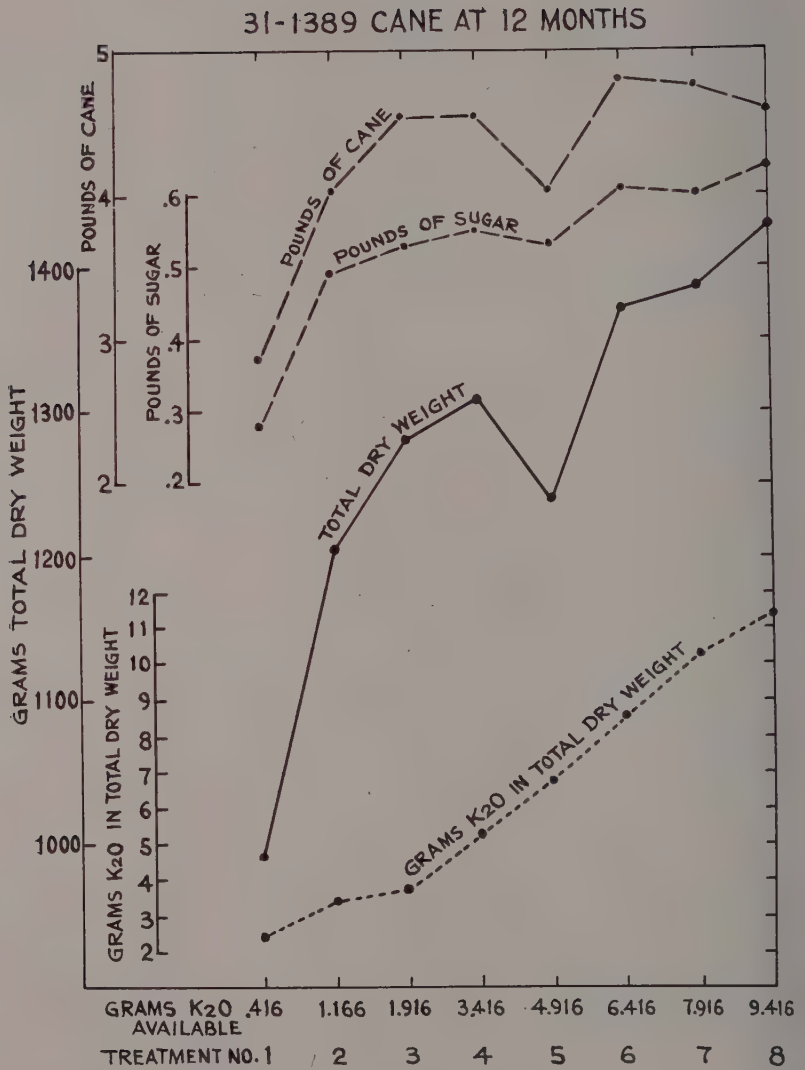
Fig. 2

Fig. 3

TABLE IV

POTASH RECOVERED ON VARIETY H 109 AT 12 MONTHS

Treat. No.	Gms. replace-able[1] K_2O in soil	Gms. K_2O added in fert.	Avail.[2] potash (gms.)	Total gms. dry wgt.[3] (See Table V for detail)	Grams K_2O in total dry wgt.	Percent-age of avail.[1] K_2O recovered	% K_2O in soil after harvest
1	.416	0	.416	1000	2.516	605	.0021
2	.416	.75	1.166	1083	3.559	305	.0022
3	.416	1.5	1.916	1141	4.010	·209	.0022
4 ·	.416	3.0	3.416	1246	7.103	208	.0022
5	.416	4.5	4.916	1251	7.633	155	.0024
6	.416	6.0	6.416	1250	8.788	137	.0027
7	.416	7.5	7.916	1282	9.692	123	.0027
8	.416	9.0	9.416	1310	12.380	131	.0027

[1] R.C.M. K_2O in soil $\times$ 3.3.

[2] Replaceable K_2O plus K_2O added from fertilizer.

[3] Dry weight of trash and tops, bagasse, roots, and solids in juice.

TABLE V

DETAILS OF DRY WEIGHTS AND K_2O RECOVERED IN VARIETY H 109

Treatment No.	Bagasse			Crusher juice			
	Gms. dry wgt.	% K_2O	Gms. K_2O	Gms. solids in juice	Gms. juice	% K_2O in juice	Gms. K_2O
1	287	.120	.344	107	745	.020	.149
2	311	.122	.379	130	844	.020	.172
3	343	.148	.508	134	876	.020	.175
4	379	.146	.553	161	958	.020	.192
5	393	.171	.672	166	1011	.020	.202
6	381	.212	.808	161	975	.023	.228
7	383	.223	.854	162	966	.027	.260
8	386	.245	.946	140	811	.043	.353
Totals (all Treatments)			5.064				1.731

Treatment No.	Trash and tops			Roots		
	Gms. dry wgt.	% K_2O	Gms. K_2O	Gms. dry wgt.	% K_2O	Gms. K_2O
1	451	.390	1.759	155	.170	.264
2	470	.581	2.731	172	.161	.277
3	488	.610	2.977	176	.199	.350
4	517	1.149	5.940	189	.221	.418
5	522	1.234	6.441	170	.187	.318
6	518	1.426	7.387	190	.192	.365
7	543	1.498	8.134	194	.229	.444
8	570	1.860	10.602	214	.224	.479
Totals (all Treatments)			45.971			2.915

Grams K_2O recovered:

$$\text{Trash} + \text{Tops} + \text{Roots} \quad 48.886$$
$$\text{Bagasse} + \text{Juice} \quad 6.795$$

(a) From all Treatments: Ratio of $\dfrac{\text{Trash} + \text{Tops} + \text{Roots}}{\text{Bagasse} + \text{Juice}} = \dfrac{48.886}{6.354} = 7.2.$

(b) From Treatment No. 4 only: Ratio of $\dfrac{\text{Trash} + \text{Tops} + \text{Roots}}{\text{Bagasse} + \text{Juice}} = \dfrac{6.354}{.745} = 8.5.$

TABLE VI

SUMMARY OF YIELDS

VARIETY 31–1389 AT 12 MONTHS

(Averages of 3 Pots)

Treatment No.	Gms. K_2O added	Stalk diameter (inches)	Cane (lbs.)	Brix	Purity	Y%C	Sugar (lbs.)
1	0	.92	2.81	16.2	82.3	9.62	.28
2	.75	1.04	4.01	18.9	86.8	12.22	.49
3	1.5	1.07	4.55	18.4	85.3	11.59	.53
4	3.0	1.05	4.56	18.8	86.7	12.13	.55
5	4.5	1.15	4.04	19.2	89.1	12.99	.53
6	6.0	1.14	4.79	19.2	88.5	12.83	.61
7	7.5	1.09	4.75	18.9	88.5	12.63	.60
8	9.0	1.13	4.61	20.1	90.6	13.96	.64
Minimum difference required for significance		.10	.65	1.1	3.1	1.59	.11

TABLE VII

POTASH RECOVERED IN VARIETY 31–1389 AT 12 MONTHS

Treatment No.	Gms. replaceable[1] K_2O in soil	Grams K_2O added in fert.	Avail.[2] K_2O gms.	Total gms. dry wgt.[3] (See Table VIII for detail)	Grams K_2O in total dry wgt.	Percentage of available[1] K_2O recovered	% K_2O in soil after harvest
1	.416	0	.416	991	2.405	578	.0022
2	.416	.75	1.166	1203	3.310	284	.0022
3	.416	1.5	1.916	1279	3.767	197	.0022
4	.416	3.0	3.416	1308	5.267	154	.0025
5	.416	4.5	4.916	1237	6.896	140	.0022
6	.416	6.0	6.416	1373	8.504	133	.0024
7	.416	7.5	7.916	1381	10.279	130	.0024
8	.416	9.0	9.416	1428	11.417	120	.0024

[1] R.C.M. K_2O in soil $\times$ 3.3.

[2] Replaceable K_2O plus K_2O added from fertilizer.

[3] Dry weight of trash and tops, bagasse, roots, and solids in juice.

TABLE VIII

DETAILS OF DRY WEIGHT AND K_2O RECOVERED IN VARIETY 31–1389

Treatment No.	Bagasse Gms. dry wgt.	% K_2O	Gms. K_2O	Crusher juice Gms. solids in juice	Gms. juice	% K_2O in juice	Gms. K_2O
1	236	.113	.267	82	502	.020	.100
2	337	.139	.468	144	763	.020	.152
3	360	.124	.446	173	923	.020	.185
4	362	.131	.474	158	893	.020	.182
5	331	.168	.556	145	754	.030	.226
6	392	.152	.596	176	922	.020	.184
7	382	.224	.856	163	860	.037	.318
8	380	.263	.999	174	872	.050	.436
Totals (all Treatments)			4.662				1.783

Treatment No.	Trash and tops Gms. dry wgt.	% K_2O	Gms. K_2O	Roots Gms.	%	Gms.
				198	.197	.390
1	475	.347	1.648	218	.180	.392
2	504	.456	2.298	198	.192	.380
3	548	.503	2.756	232	.281	.652
4	556	.712	3.959	dry wgt.	K_2O	K_2O
5	549	1.031	5.660	212	.214	.454
6	575	1.251	7.193	230	.231	.531
7	593	1.436	8.515	243	.243	.590
8	613	1.511	9.262	261	.276	.720
Totals (all Treatments)			41.291			4.109

Grams K_2O recovered:

(a) From all Treatments: Ratio of $\dfrac{\text{Trash} + \text{Tops} + \text{Roots}}{\text{Bagasse} + \text{Juice}} = \dfrac{45.400}{6.445} = 7.0.$

(b) From Treatment No. 6 only: Ratio of $\dfrac{\text{Trash} + \text{Tops} + \text{Roots}}{\text{Bagasse} + \text{Juice}} = \dfrac{7.724}{.780} = 9.9.$

H 109 Cane:

In Table III we show the effects from different amounts of available potash upon the yields and cane quality that were obtained. It will be noted that Treatment No. 4 has produced a cane and sugar yield that was not significantly improved when larger amounts of potash were available, and we propose to assume that this treatment was the optimum for the variety H 109.

From Table IV it is apparent that increases in the total dry weights and in the amounts of potash recovered in this dry weight have a linear relationship to amounts of potash (original plus added) in the soil in which this cane was grown. After harvest, the amount of available potash that was left in this soil was certainly not greater than was there when the cane was planted. Hence we may assume that not only did this cane during its 12-month growth period take up all of the potash that had been supplied in the fertilizers, but also that every treatment took more out of the natural soil supply than we had estimated was available. Moreover according to the percentages of available K_2O that were recovered in the crop harvested, it would appear that the drain on the soil's original potash supply was considerably greater when potash fertilization was either omitted entirely or supplied in the smaller amounts.

A study of the optimum treatment, No. 4, shows that the crop started off with a supply of 3.416 grams of available potash, and that during the subsequent 12 months it was able to pick up from some form of potash (which also must have become available) in this soil an additional 3.687 grams, for at harvest we were able to find a total of 7.103 grams in the total dry weight that had been produced. Even this total amount found in the cane from Treatment No. 4 was less than that recovered from Treatments 5, 6, 7 or 8 which we have already noted did not produce significantly more millable cane or sugar than No. 4. So here again we have more evidence of a luxury absorption of potash far in excess of the actual needs for a 12-month crop.

On the assumption that the optimum yield of 4.68 pounds of cane produced by Treatment No. 4 required a total of 7.103 grams of potash, we may estimate* an equivalent need of 235 pounds of K_2O per acre for a 12-month crop of H 109. Since the millable cane yield at this age is estimated at 35 tons†, there has been a potash-plant-food requirement of 6.7 pounds per ton of cane. This figure, how-ever, must not be construed as the potash fertilizer requirement that will be neces-sary to maintain optimum yields on this soil, for the data in Table V indicate that only a small part of this total potash was found in the bagasse and crusher juice from the millable stalks. Hence under field conditions, the potash in the roots and also that in the trash and tops, provided it remains in the field and is not lost by leaching or tied up in weed growth, will be left for use by the subsequent crop. On this basis our Treatment No. 4 with its .553 + .192 or .745 gram of potash in the bagasse and crusher juice would only remove from the field the equivalent of 25 pounds K_2O per acre or .7 pound K_2O per ton of stalks milled.

31–1389:

Table VI gives the yield data for the variety 31–1389, and we have an indi-cation that the optimum treatment for this variety has been No. 6. Once again luxury consumption of potash is indicated in Table VII, for Treatment Nos. 7 and 8 have taken up considerably more potash than No. 6, without, however, producing significantly greater yields.

As was the case with H 109, the uptake of K_2O and its recovery in the dry matter harvested have exceeded the available supply of this nutrient, and it is again evident that the drain on the natural supply of soil potash (per cent of available K_2O recovered) has been in an inverse relationship to the amounts we have estimated as being available potash. The so-called "available" amounts left in the soil at harvest are slightly less than were there at the start.

In connection with Treatment No. 6 we find that it had an estimated supply of available potash of 6.416 grams at planting, and managed to secure an addi-tional 2.088 grams while growing on this soil, for we recovered a total of 8.504 grams in the total dry matter harvested.

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* $\dfrac{7.103 \text{ grams}}{2 \text{ stalks}}$ = 3.55 grams per stalk $\times$ 30,000 stalks per acre.

† $\dfrac{4.68 \text{ lbs.}}{2 \text{ stalks}}$ = 2.34 lbs. per stalk $\times$ 30,000 stalks per acre.

These 8.504 grams of potash which were taken up by the optimum treatment for 31–1389 are probably equivalent to 280 pounds* per acre for a 12-month crop. Since its millable cane yield was equivalent to 36 tons† per acre, the potash requirement for this variety has been 7.8 pounds per ton, which is a somewhat higher requirement than we found for H 109 and bears out a general belief that this variety needs more potash than H 109.

As was the previous case however, this figure of 7.8 pounds of K_2O for a ton of 31–1389 millable cane does not necessarily mean that this amount is what must be supplied from fertilizer, for the data in Table VIII show that most of this potash will stay in the field if only the stalks are taken out. Thus in Treatment No. 6, only .596 + .184 or .780 gram of potash was contained in the bagasse and crusher juice, and this would be the equivalent of only 26 pounds of K_2O per acre—which amounts to the same figure of .7 pound of K_2O for each ton of stalks milled that we found for the variety H 109.

Discussion:

The data concerned with H 109 and 31–1389 are difficult to compare with that from POJ 2878 in the former study because of differences in their ages and growing seasons, and because we did not actually segregate for separate analyses the POJ 2878 tops and trash from the stalks. Thus it is somewhat futile to make many comparisons between the two studies.

It is not at all unlikely that the low figure of .7 pound K_2O, that went from the field with each ton of either 31–1389 or H 109 stalks, explains why we have been able to grow and take off large cane crops year after year by supplying from fertilizers only a small part of the total potash that is taken up from the soil by such crops.

It must be remembered that we have secured our data from carefully controlled pot studies in which there were no losses of potash (a) through leaching from the soil or the dry leaves, or (b) by weed uptake. Thus we were able to secure nearer 100 per cent efficiency from the potash fertilizer which we used than will be possible in a general field practice. Furthermore there was no loss of any plant material from our canes during their whole 12-month growing period.

The fact that not more than one seventh of the total potash taken up by 31–1389 and H 109 was found in the stalks after 12 months of growth means that the actual losses of potash in crops taken from our continuously cropped soils are not very large, and that a moderate potash fertilization should maintain a satisfactory status of this plant food, if the cane stalks only are taken from the field. However, with machine harvesting methods that tend to send large amounts of trash out of the field, we will certainly have to increase the potash applications for the low potash soils above those normally used when all trash is left in the field— whether it is burned or unburned.

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* $\dfrac{8.504 \text{ grams}}{2 \text{ stalks}} = 4.252$ grams per stalk × 30,000 stalks per acre.

† $\dfrac{4.79 \text{ lbs.}}{2 \text{ stalks}} = 2.395$ lbs. per stalk × 30,000 stalks per acre.

Summary:

In connection with the formulation of a sound policy of potash fertilization, the results which have been secured from this investigation indicate that we must differentiate between potash uptake by the sugar cane crop and its potash requirement for optimum yields, because a luxury consumption of potash by the cane plant has been clearly shown.

When only the millable cane stalks leave the field, the actual amount of potash that goes with them is not very large. Hence although the total potash taken out of the soil by the growing crop may have been quite large, much of this potash will be left in the trash, tops, and roots in the field.

We have apparently found an indication that the sugar cane plant was able to absorb some potash from a non-exchangeable form that existed in the soil, although the amount taken up was not adequate for optimum yields. There is also an indication that some of the applied soluble potash salts were fixed in the soil in a non-exchangeable form.

Since the ratio of tops and trash to the millable stalks is higher in young than in older cane, and as the per cent K_2O is also higher in the tops and trash than in the stalks, our short crops are going to need potash at a higher rate per ton of millable cane expected than our long crops. However, since these short crops will leave a large amount of their absorbed potash in the tops and trash which are left in the field, a subsequent crop should be able to recover some of this potash.

The fact that we *have* obtained responses in field experiments on low potash soils to applications of 250 pounds K_2O per acre with 2-year old cane crops averaging around 70 tons may mean that we have not secured the full efficiency of these heavier applications. The fact that we *have not* obtained responses to K_2O in some of our field experiments on low potash soils may be because a heavy potash fertilization for a previous crop has furnished a luxury supply which has (a) either become fixed in the soil, (b) been taken up from the soil (and so is not identified in the usual soil analysis), or (c) stored in the leaves and roots and is eventually released therefrom and made available to subsequent crops.

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Sugar Prices

96° CENTRIFUGALS FOR THE PERIOD
DECEMBER 16, 1940, TO MARCH 14, 1941

Date	Per pound	Per ton	Remarks
Dec. 16, 1940.......	2.90¢	$58.00	Philippines.
" 19............	2.93	58.60	Puerto Ricos.
" 28............	2.91	58.20	Philippines, Cubas.
" 30............	2.90	58.00	Cubas.
Jan. 4, 1941.......	2.91	58.20	Philippines.
" 7............	2.90	58.00	Philippines.
" 8............	2.92	58.40	Philippines, 2.91; Puerto Ricos, 2.93.
" 14............	2.925	58.50	Philippines.
" 18............	2.92	58.40	Philippines.
" 22............	2.93	58.60	Cubas, Philippines.
" 28............	2.97	59.40	Philippines.
" 29............	2.935	58.70	Cubas, Puerto Ricos, 2.93; Cubas, 2.94.
" 31............	2.95	59.00	Philippines.
Feb. 5............	2.94	58.80	Cubas, Puerto Ricos, Philippines.
" 6............	2.945	58.90	Philippines, 2.94, 2.95.
" 7............	2.945	58.90	Philippines, 2.95; Cubas, 2.94.
" 8............	2.95	59.00	Cubas.
" 10............	2.94	58.80	Puerto Ricos.
" 11............	2.955	59.10	Puerto Ricos, 2.94; Philippines, 2.97.
" 13............	2.98	59.60	Philippines.
" 17............	3.00	60.00	Philippines.
" 18............	2.99	59.80	Puerto Ricos, 2.98; Cubas, 3.00
" 19............	3.00	60.00	Puerto Ricos.
" 20............	3.0267	60.53	Cubas, 3.00; Puerto Ricos, 3.03; Cubas, Puerto Ricos, 3.05.
" 21............	3.05	61.00	Puerto Ricos.
" 25............	3.11	62.20	Philippines, Puerto Ricos, Cubas, 3.10; Philippines, 3.12.
" 27............	3.15	63.00	Puerto Ricos, Cubas.
Mar. 7............	3.20	64.00	Puerto Ricos.
" 12............	3.265	65.30	Cubas, 3.25; Philippines, 3.28.
" 13............	3.28	65.60	Puerto Ricos.
" 14............	3.30	66.00	Cubas, Puerto Ricos.

THE HAWAIIAN PLANTERS' RECORD

H. L. Lyon, *Editor*

EXPERIMENT STATION STAFF

H. L. Lyon, Director

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